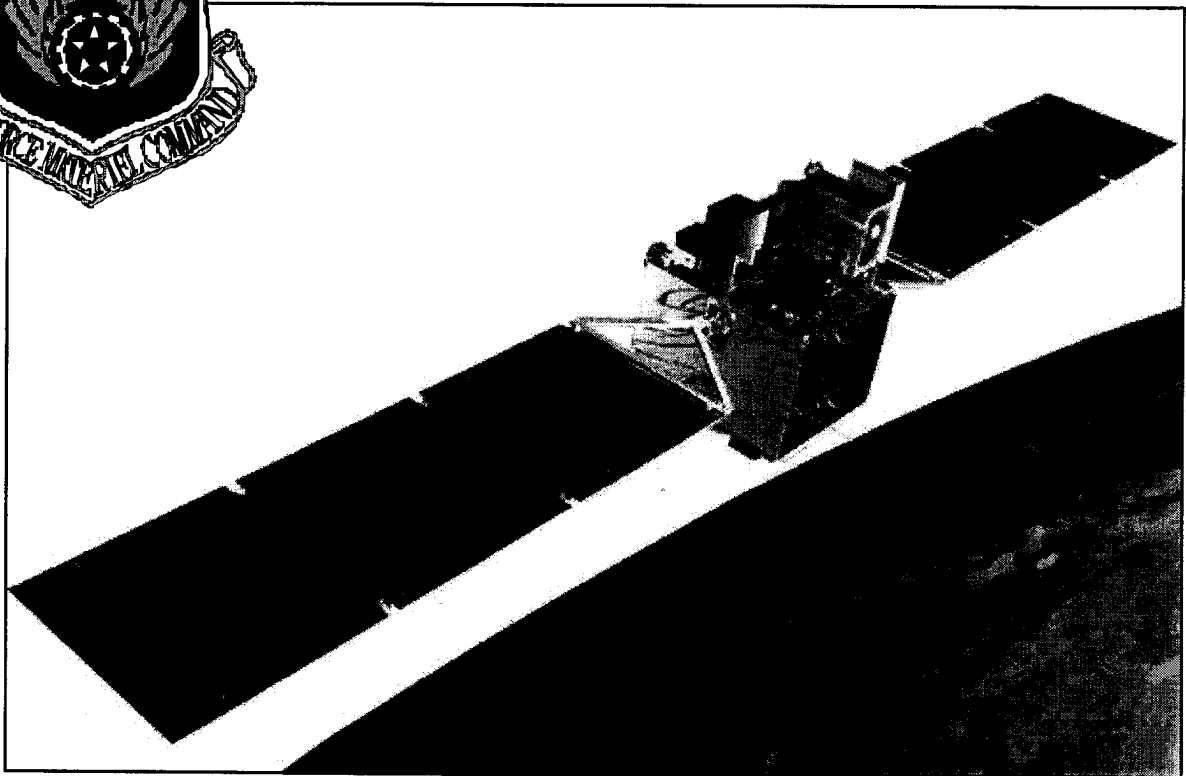


# **FY98 SPACE AND MISSILES TECHNOLOGY AREA PLAN**



**HEADQUARTERS AIR FORCE MATERIEL COMMAND  
DIRECTORATE OF SCIENCE & TECHNOLOGY  
WRIGHT PATTERSON AFB, OH**

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**Note:** This Technology Area Plan (TAP) is a planning document for the FY98-03 S&T program and is based on the President's FY98 Budget Request. It does not reflect the impact of the FY98 Congressional appropriations and FY98-03 budget actions. You should consult PL/XP, DSN 246-4962 or Commercial (505) 846-4962 for specific impacts that the FY98 appropriation may have had with regard to the contents of this particular TAP. This document is current as of 1 June 1997."

#### **About the cover:**

Pictured on the cover is an artist's concept of the MightySat II spacecraft. Orderly and routine demonstrations provide flight heritage of emerging space and missile technologies prior to their transition to the operational user. MightySat II is a three-axis stabilized spacecraft generating 325 watts of power for satellite and payload operations. The first of a series of five spacecraft will fly in FY00, flying nine experiments developed under the Space and Missiles and Directed Energy TAPs. Among the Space and Missile technologies aboard MightySat II are multifunctional structures, the isogrid solar array, composite structures, shape memory alloys and Microsystem and Packaging for Low Power Electronics (MAPLE). MightySat is tailored to fly technologies developed within the Air Force laboratories and supports the test of payloads as well as experimental bus components.

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# VISIONS & OPPORTUNITIES

## Space & Missiles

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Rapid and cost effective research, development and transition of advanced space technologies enables affordable and decisive military capabilities for US forces. The Space and Missiles Technology Area Plan is developing technologies that provide options for the warfighter that take maximum advantage of space as an operating environment. In the face of declining budgets and manning levels, constraints are placed on the S&T programs. We constantly strive to make technology investments in the high payoff areas. Our investment strategy emphasizes improved productivity at reduced cost. The need for affordability is a pervasive requirement that is emphasized throughout all aspects of the Space and Missiles Technology Area Plan.

The breadth of technologies pursued in the Space and Missile Technology Area Plan is driven by specific military operational needs described in the Future Joint Warfighting Capabilities. These are:

1. To maintain near perfect knowledge of the enemy and communicate that to all forces in near-real time.
2. To engage regional forces promptly in decisive combat, on a global basis.
3. To employ a range of capabilities which allow achievement of military objectives with minimum casualties and collateral damage.
4. To control the use of space.
5. To counter the threat to the CONUS and deployed forces of future ballistic cruise missiles and other weapons of mass destruction.

We respond to these warfighter needs through the Air Force mission area planning process. The Air Force operational needs are described in terms of deficiencies, operational concepts, and technology needs to meet user requirements.

Our technology investments in support of the warfighter will be focused into Global Engagement and Global Presence, or what we call Global Virtual Presence. Global Virtual Presence is the ability to know and understand what is happening anywhere, anytime in the battlespace environment, and to be able to engage militarily, in real or near real time, with graduated levels of response, to meet national objectives. Global Engage-

ment, Global Presence -- instant awareness, global dominance in air and space, and omnipresence with space based sensors and weapons - will allow proactive reactions with a wide range of graduated levels of response to a wide variety of levels of tension in the battlefield of the 21st Century.

We implement the over arching vision of Global Virtual Presence by formulating four major technology Enterprises that provide focus and direction to our technology investment plans.

These four Enterprises are:

- Protection Enterprise
- Space Force Projection Enterprise
- Remote Sensing and Surveillance Enterprise
- Space Operations Enterprise

The underlying technology base conducted in the Space and Missiles Technology Area Plan cuts across, and to some degree is interwoven between, these four Enterprises.

The Protection Enterprise provides focus and direction to technology investments that assure the survival of our space systems, whether the threat is natural or man-made. This Enterprise is broadly defined to address everything from radiation hardened electronics and sensors to threat warning and attack reporting. It will include both passive and active techniques for self protection as well as the development of protocols for debris management and mitigation. In addition, a major objective in this enterprise is to advance the understanding of the



effects of interactions between the environment and military systems and provide guidance to designers of advanced systems to ensure increased survivability and reduced weight and cost. Our space assets and capabilities must have assured survivability at any level of adversarial hostility.

The Space Force Projection Enterprise provides focus and direction to technology investments that address the application of force from and through space to points in space, in the air and on the ground. The scope of this Enterprise is wide and includes leading technology initiatives in areas such as the Military Space Plane, Space Based Lasers and ballistic missile systems. Though current treaty implications limit the actual fielding of weapons in space, low end capabilities providing entry levels of graduated deterrence are needed now. The technology base required to meet future space weapon needs must be developed and matured today if it is to be available for future warfighter needs.

The Remote Sensing and Surveillance Enterprise provides focus and direction to active and passive technology investments that assure innovative and revolutionary techniques for detecting and determining adversarial threats. This investment will form the foundation of the tactical situation awareness for the 21st Century. Classical, wide area surveillance will continue to be a critical Air Force mission area, but this Enterprise will specifically address advanced technologies for tactical theater area interrogation and high value targeting that will be used for cueing other sensor and weapon systems. A critical part of theater information will be the knowledge of the battlespace environment, and this Enterprise will provide the capability to observe, model, and predict environmental conditions encountered by the warfighter at any time, anywhere on the globe. These revolutionary remote sensing tools will allow a level of situational awareness on the ground, in the air and in space that has never before been available to the warfighter.

The Space Operations Enterprise provides focus and direction to technology investments critical to the increasingly important operation of the Air Force in space. Satellite autonomous operation will usher in a new era of "information on demand" satellite systems, with interconnected constellations of satellites precisely providing the information that the warfighter needs, when it's

needed, where it's needed. Mobility in space coupled with less expensive and easier access to space is a key to Air Force dominance of the space arena. Decision aids must be developed for mission planning and operations that specify the expected performance of military systems based on anticipated conditions in the environment. The Air Force of the 21st Century will have to move in and through space with the same ease that it now moves in and through the atmosphere. Orbit transfer propulsion systems will be key to this essential capability. Space systems will cost less, last longer, and perform better through improved capabilities in payload thermal management; payload stabilization; power generation, storage and management; on-board processing capability, data processing and communication. Deploying these capabilities in the space environment will be made more affordable through investments in lighter and higher performance lift systems, improvements in design, integration, and operation processes, component weight reduction, and operation and control technologies.

To meet these aggressive goals for the Air Force's role in Space, we will leverage our efforts with industry and other government agencies to mutually exploit technology innovation as part of our vision for future technology development and transition. An emphasis is placed on direct commercial exploitation, assessment of commercial off-the-shelf technology for military application, and cooperative research and development with industry, academia and other space focused government organizations.

The situational awareness afforded throughout the battlespace -- on the surface of the earth, in the air and in space -- provides the means for aerospace supremacy, enabling the full range of options for other weapons systems employed in the theater. These investments provide the nation not only a precision, global strike capability with minimum casualties and collateral damage, but also the possibility of strategic deterrence, flexible responses, and the ability to influence events in real time, thereby providing the warfighter with a continuous range of response options, varying from lethal to non-lethal. This is Global Virtual Presence and this is the vision of the Space and Missiles Technology Area Plan. We have the opportunity to lead the Air Force into the Space Force of the 21st Century.

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*"This plan has been reviewed by all Air Force laboratory commanders/directors and reflects integrated Air Force technology planning. I request Air Force Acquisition Executive approval of the plan."*

RICHARD R. PAUL  
Major General, USAF  
Technology Executive Officer

MICHAEL L. HEIL, Colonel, USAF  
Commander  
Phillips Laboratory

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# INTRODUCTION

## Space & Missiles

### BACKGROUND

The Space and Missiles Technology Area, highlighted in Figure 1, is that part of the Air Force Science and Technology (S&T) Program charged with developing evolutionary and revolutionary technology for space and ballistic missile systems. It also includes the former Geophysics Technology Area, which advances Air Force warfighting capabilities by providing technology to define, understand, and control interactions between all Air Force systems and their battlespace environment.

The programming reflected in this Technology Area Plan (TAP) is coordinated and aligned with various Technical Planning Integrated Product Teams (TPIPT) to address user requirements and provide visionary opportunities for technology push. The TPIPTs, in turn, receive far- and near-term requirements of the space and missile community both through the validated MAJCOM requirements in the Mission Need Statements, Operational Requirements Documents, and Mission Area Plan (MAP) Deficiencies. Technology requirements to support advanced systems are generated by the Product Divisions with laboratory support. Both technology push and

pull enable substantial payoffs for AF systems.

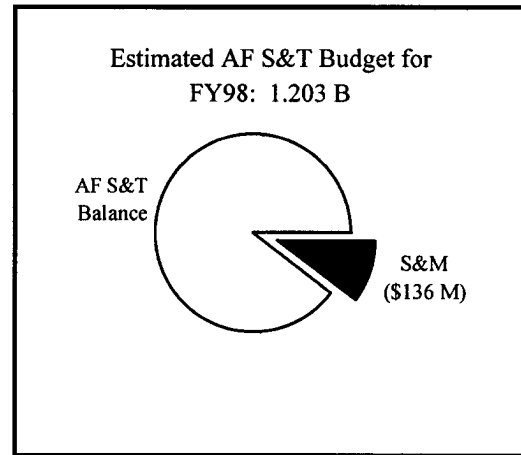


Figure 2: S&M S&T \$ vs AF S&T \$

This document details the implementation of the Space Force Enhancement TPIPTs' technology development plans and includes needs, goals, major accomplishments, and changes from last year.

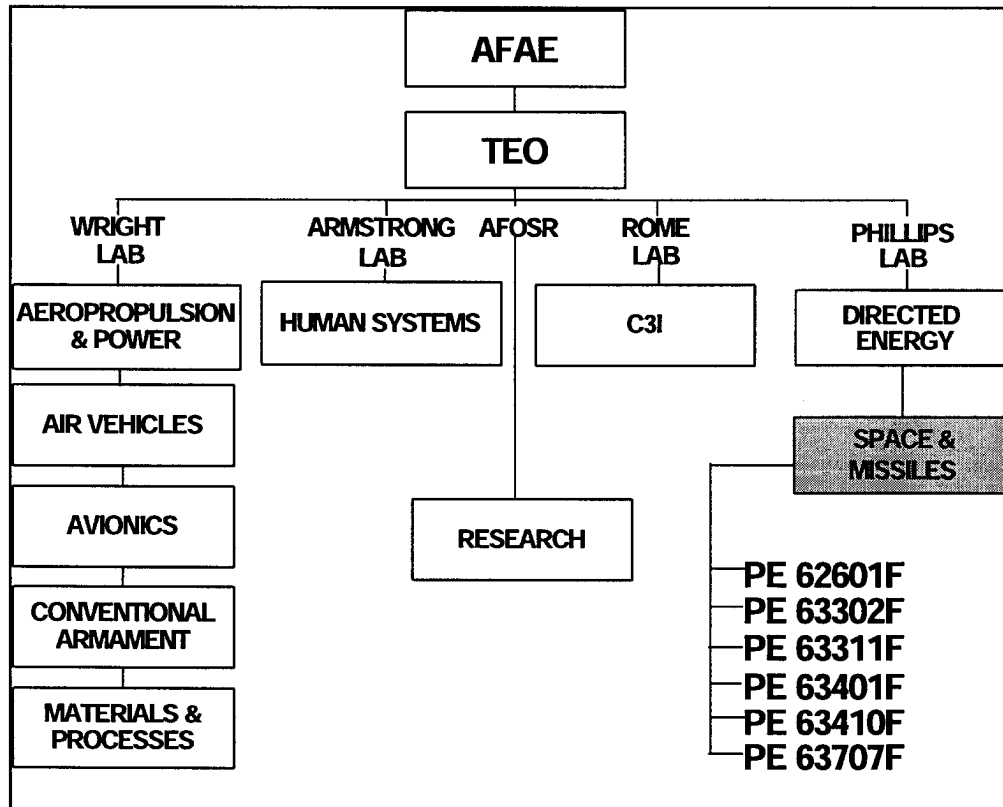


Figure 1: Air Force Science and Technology Program Structure

The program described in this TAP is subject to change based on possible congressional action.

The President's FY98 Budget Request includes an AF S&T funding total to Phillips Laboratory (PL) approaching \$136M to perform exploratory and advanced technology development for the Space and Missiles Technology Area (ref. Figure 2). Additionally, Ballistic Missile Defense Organization (BMDO), Defense Advanced Research Projects Agency (DARPA), NASA, and others also provide significant funding to PL for Space and Missile S&T (ref. Figure 3). The total budget is dis-



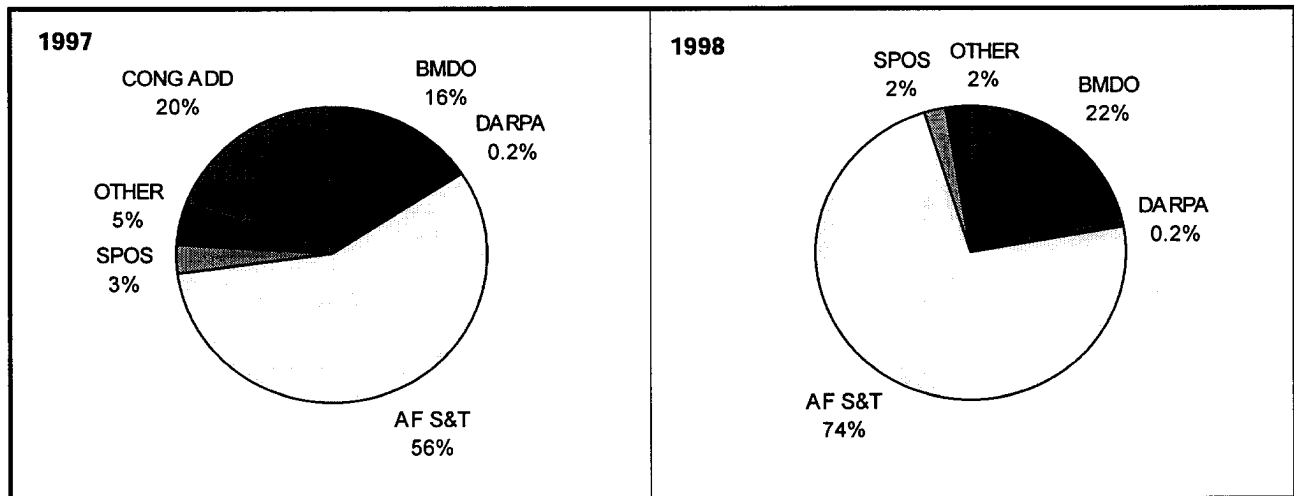


Figure 3: FY97 and FY98 Total Space & Missiles Funding

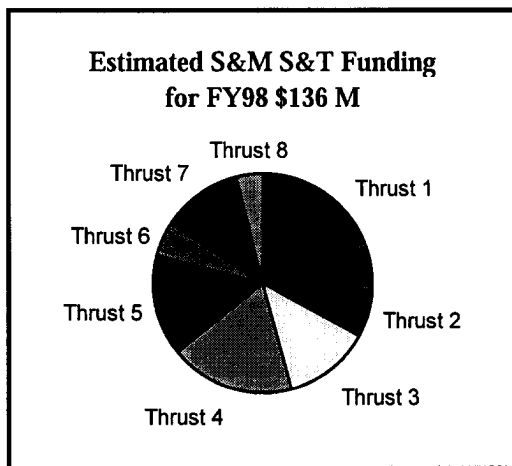


Figure 4: Major S&M Technology Thrust Funding

tributed across a range of both in-house and contractual programs.

Maximum leverage of these R&D investments is accomplished through the broad base of the Space and Missiles Technology Area supporting many AF mission areas. Towards meeting these AF, and DoD, mission area needs, technology efforts in the Space and Missiles TAP are managed along eight technology thrusts, as listed in Table 1 and funding among these thrusts as shown in Figure 4:

Table 1: S&M Technology Thrusts

1. Boost and Orbit Transfer Propulsion Technology
2. Spacecraft and Tactical Propulsion Technology
3. Space Vehicle Technologies

4. Advanced Space Technology Integration and Demonstration
5. Space Mission Technologies
6. Space System Technologies
7. Battlespace Communications and Operations
8. Optical Surveillance Effects and Battlespace Operations

The majority of the S&T programs in these technology thrusts proceed from basic research, to exploratory development, to advanced technology development, and indeed to technology transfer/transition. (Exception: Geophysics programs differ from other technology areas in that the advanced technology program delivers many S&T products directly to customers for operational development, such as the 55<sup>th</sup> Space Weather Squadron, rather than to an intermediary SPO.)

Recent accomplishments in the Technology Thrusts follow:

- A small Solid Oxygen (SOX) Engine was developed and fired. This project demonstrated that cryogenic solids can be burned in a hybrid rocket geometry. Solidifying the oxygen increases the oxidizer density and provides a means of storing other energetic oxidizers, such as ozone. Adding 50% ozone in solid oxygen increases the specific impulse of a hydrogen-oxygen/ozone system by 20 sec.
- In the composite space vehicles area, two significant events occurred. The first was a successful flight demonstration of a composite shroud on the BMDO Combined Experiments Program (CEP). This flight demonstrated a 61% mass savings and 88% savings in manufacturing time over conventional shrouds. The second accomplishment was the delivery of the Advanced Composite Experimental Spacecraft Structure (ACCESS), which will be used on STRV-2. This payload module demonstrates a low-weight, low cost uni-body construction for satellites.

- The multi-junction ManTech Solar Cell program demonstrated a photovoltaic array with a lot average conversion efficiency of 24.2% for the first time. This represents a 33% improvement over conventional GaAs solar cells and paves the way for meeting the higher power requirements of future communications satellites.
- The thermal management technology area had a successful flight demonstration of the liquid metal heat pipe on STS-77. This demonstrated the highest ever operating temperature for a heat pipe, approximately 900°C.
- A flight of the Missile Technology Demonstration 2 (MTD 2) was conducted on 29 January 1997. MTD 2 tested range safety, missile electronics, and penetrator technologies for ballistic missiles. MTD 2 utilized an active on-board differential GPS/IMU for flight navigation in addition to the range safety metrics demonstrated on the flight's predecessor, MTD 1. Three GPS/INS packages were independently demonstrated on the flight.
- By reconfiguring the design of the Advanced Technology Insertion Module Single Board Computer and using an advanced Aluminum Nitride substrate, a double-sided 32-Bit Multichip Module (MCM) was successfully designed and prototyped. This design reduced the weight by 10X, size by 15X and provided the same functionality as the larger version.
- Through innovative design and advanced packaging applications, a credit-card-size, 70V bus, >90% efficient distributed payload power converter (EHF Payload Power Converter) was developed. The new design eliminates virtually 80 pounds per converter, and reduces the volume from ~ 3 cu-ft to ~0.001 cu-ft.
- A GPS Anti-Jam Filter was developed that removes the effects of five jamming frequencies of various narrow-band formats and reconstructs the GPS signal with greater than a 95% accuracy. The design was implemented after first pass successes for an adaptive transfer filter and a 12-bit analog-to-digital converter. The module can be used in a real sampling-double channel mode of a complex sampling-single channel mode; if two modules are used, complex sampling-double channel mode can be implemented.
- A prototype Scintillation Network Decision Aid (SCINDA) was installed at 55SWS to provide the warfighter with SATCOM outage regions and help plan for such outages and/or degradation of navigation. This aid also helps identify the source of the outage: equipment failure, jamming or ionospheric effect.
- Research in energetic materials flows directly into the Applied Research In Energy Storage (ARIES) program investigating High Energy Density Matter (HEDM)
- Aerospace science research feeds investigations of combustion mechanisms, plume phenomena, and plasma diagnostics
- Space vehicle efforts benefit from basic research in spacecraft dynamics and control phenomena
- Theoretical chemistry research in reactions of atmospheric species contribute to models of atmospheric radiation used by BMDO
- Atmospheric sciences research improves atmospheric prediction capabilities to understand atmospheric dynamics and impacts on communications and surveillance systems
- Space science research is critical to the development of future Air Weather Service space weather prediction models and future Air Force space surveillance systems. Wright Laboratory (WL) provides manufacturing and materials technology development for several thrusts:
- Manufacturing Technology (MANTECH) provides methodologies for scaling research materials into production quantities. Selected propulsion technology components have been carried from exploratory through advanced development and become candidates for MANTECH demonstrations. The Materials Technology Area (WL/ML) develops materials and processes for lightweight structural applications, high-efficiency multi-junction solar cells, high temperature rocket engines, thermal protection, sensors and communication, and survivability from laser threats. In a partnership with PL, WL/ML transitions materials technologies to support PL satellite, launch, and propulsion technologies.
- Other examples of cooperative programs with WL include obtaining infrared (IR) signatures and predictive models of aircraft for Air Vehicles. Geophysics programs lead in working with the Avionics TA in using Lidar to measure winds aloft as well as aiding in defining trajectories of bombs. Avionics leads in using Lidar to correct the trajectories of cargo, pallets, and projectiles originating from aircraft.

Rome Laboratory conducts joint ionospheric radio frequency (RF) propagation experiments; and Armstrong Laboratories is provided with space radiation human hazard data.

Rome Laboratory (RL) and WL conduct 6.1 and 6.2 technology programs in the areas of antennas, component reliability, software, photonics, communications, and signal processing, which have been transitioned to PL 6.2 and 6.3 technology efforts.

PL is an active member on joint government and industry teams working to develop space power technologies for primary and secondary spacecraft systems:

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## RELATIONSHIP TO OTHER TECHNOLOGY PROGRAMS

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The Air Force Office of Scientific Research (AFOSR) supports numerous PL basic research efforts including:

- Lithium ion battery technology is being developed in close coordination with WL and other AF agencies.
- NASA supports the development of both nickel hydrogen IPV and CPV designs.
- The primary battery program is strongly supported by industry for insertion into commercial launch vehicles.
- A new Flywheel Energy Storage and Attitude Control Program initiated in partnership with NASA/LeRC aims to increase the energy storage lifetime for LEO satellites by a factor of three while significantly reducing the combined masses of conventional energy storage/attitude control systems.

The Space and Missile TA also has joint activities with other government organizations, including:

- All of PL's rocket propulsion programs support the Integrated High Payoff Rocket Propulsion Technology (IHRPT). IHRPT is an Air Force, Army, Navy, NASA and industry effort to double rocket propulsions capabilities by the year 2010
- Antenna and EHF component development efforts collaboratively within Rome Laboratory's C3I TAP
- Development of infrared sensors for the Air Force Maui Optical Site (AMOS) and Starfire Optical Range; characterization of atmospheric optical turbulence and its effects on laser systems; and remote sensing using Lidars are coordinated efforts with the Directed Energy TA
- Development of technologies for Advanced MIL-SATCOM program office
- Integration of various databases being developed on radar clutter backgrounds for modeling signal processing algorithms with Lincoln Labs, NASA (under the SIR-C and XSAR shuttle programs), and Georgia Tech Research Institute
- BMDO funded programs in support of kinetic energy weapons; plume phenomenology; small, modular satellites; Advanced Liquid Axial Stage, and Advanced Solid Axial Stage propulsion systems; adaptive structure technology development; precision pointing experiments; and high reliability, low temperature cryocoolers for cooling IR focal planes and optics
- Development of EHF antenna technology and GPS Guidance Package with DARPA
- Development of high-density memory modules with NASA Goddard Space Flight Center for two satellite programs, and production of space-qualified single-layer modules and multi-layer modules next year
- Joint data collection efforts with NASA/JPL SIR-C/X-SAR and TOPSAT critical to active sensor work in the AF
- Modeling and simulation (M&S) efforts supporting the Army's obscurants modeling and transporter - erector - launcher live simulator development, and the Naval Postgraduate School's Unmanned Aerial Flight Simulator

- Passive sensor efforts to address deficiencies in the Army's USASSDC sensor packaging program
- Coordination of programs with Rome Laboratory, NASA, Wright Laboratory and the other Services in Communications, Sensors, and Processing and Electronics
- A joint effort with the Army, Navy, and other Air Force agencies to support the Hardened and Deeply Buried Targets Defeat Capability (HDBTDC) ACC/STRATCOM Mission Needs Statement (PL integrates HDBTDC needs into its Ballistic Missile Technology efforts through its Missile Technology Demonstration flights.)
- System checkout of the Linear Aerospike SR-71 Experiment (LASRE) flight hardware prior to flight testing at NASA Dryden on an SR-71 aircraft (Technology, data, and lessons from this project will feed into NASA's X-33 program.)

Some international collaborative efforts include:

- Detector technology developed used by the European Space Agency (ESA) Infrared Space Observatory Spectrometer
- Development of detector material technology in conjunction with international partners
- Collaboration on the Shuttle Potential and Return Electron Experiment (SPREE) experiment on the Italian Tethered Satellite System (TSS) flown on the Shuttle (While the deployments of the TSS were unsuccessful, SPREE was an outstanding success since measurements agreed closely with predictive models on both flights, very important to the development of future large space systems.)

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## CHANGES FROM LAST YEAR

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The Space and Missiles TAP has undergone a major restructuring this past year. Thrusts three through eight have been realigned into four new thrusts. The previous Structures and Power thrusts have been combined into the new Space Vehicle Technologies thrust. The old Electronics thrust has been combined with Sensors and Communications to create the Space Mission Technologies thrust. Satellite Control and Astrodynamics have been combined into the Space Systems Technologies thrust. Finally, Missile Dynamics has been incorporated as a new subthrust of the Space Technology Integration and Demonstration thrust.

The overall reduction in the number of thrusts has been offset by the incorporation of Geophysics technology into the Space and Missiles TAP. Two new Geophysics thrusts appear this year: Battlespace Communications and Operations and Optical Surveillance Effects and Battlespace Operations.

The mapping of previous thrusts and the Geophysics TAP into the current Space and Missiles TAP is shown in Figure 5.

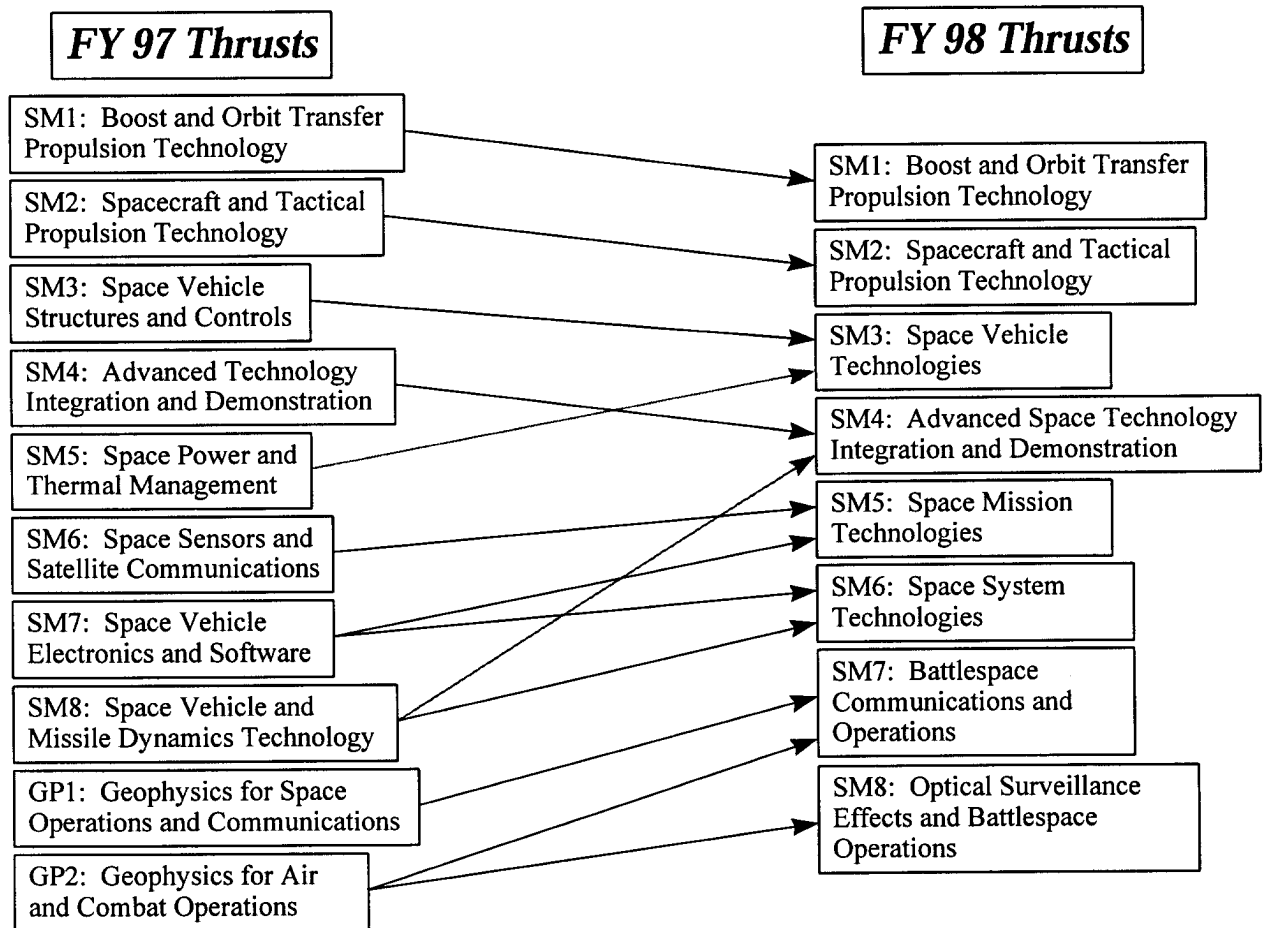


Figure 5: FY97 vs FY98 Thrust Numbering

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## THRUST 1: BOOST AND ORBIT TRANSFER PROPULSION TECHNOLOGY

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### USER NEEDS

The Air Force Policy of "Global Presence" cites Situational Awareness and Strategic Agility as tenants needing "technological innovations" to "enhance US ability to exert presence." The following SMC Development Plans and NASA requirements also demand propulsion improvements to fulfill critical deficiencies:

**Spacelift:** High Performance, Advanced, Cryogenic and Liquid Rocket Propellants and Engines, Low Cost Solid and Hybrid Motors, Low Cost Manufacturing, High Performance Low Cost Expendable Engines, Solar Thermal Propulsion (for Orbit Transfer), Advanced Orbit Transfer Concepts, and Manufacturing Technologies

**Strategic Sustainment:** Motor Aging and Surveillance

**Conventional Deterrence:** Missile Propulsion Material Applications, Global Range and Survivability, Missile Propulsion Technology, Missile Propellant Non-Destructive Test Technology, Solid Rocket Motor Manufacturing, Reliability

**Reconnaissance/Surveillance:** Large Payload Spacelift Systems

**NASA:** Advanced Reusable Spacelift, Low Cost Reliable Access to Space.

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### GOALS

The propulsion needs identified above will be fulfilled by achieving the goals set forth in the Integrated High Payoff Rocket Propulsion Technology (IHDRPT) initiative. IHDRPT's vision is to double spacelift propulsion capability by 2010 through the development of advanced, innovative rocket propulsion technology.

By 2000, the IHDRPT spacelift goals will:

- increase expendable payload to orbit capability by 9% or reusable payload to orbit capability by 71% (over the life of the reusable system) and
- reduce payload launch costs by 19%.

By 2010, the IHDRPT spacelift goals will:

- increase expendable payload to orbit capability by 22% or reusable payload to orbit capability by 206% (over the life of the reusable system) and
- reduce payload launch costs by 42%.

By 2000, the IHDRPT orbit transfer goals will:

- double repositioning capabilities (double number of repositioning maneuvers) or
- increase allowable satellite mass by 10%.

By 2010, the IHDRPT orbit transfer goals will:

- increase repositioning capability by 5 times or

- increase allowable satellite mass by 30%.

To meet the spacelift and orbit transfer propulsion goals, chemical (liquid, solid, and hybrid), solar thermal, and electrical propulsion technology development is crucial.

In response to the above needs, PL develops spacelift and orbit transfer propulsion technology for:

- high performance, low cost expendable propulsion
- advanced liquid and cryogenic reusable and expendable propulsion
- low cost, rapid prototype thrust cell and component manufacturing technology
- high energy materials for potential use as propellants
- improved ballistic missile motor service life in both existing and new systems
- dramatically reduced manufacturing and support costs.
- developing motor manufacturing processes that eliminate harmful chemicals used in motor manufacturing
- developing long life, high performance, environmentally acceptable solid propellants while maintaining properties/integrity equal to current solid propellants
- chemical and solar thermal orbit transfer applications.

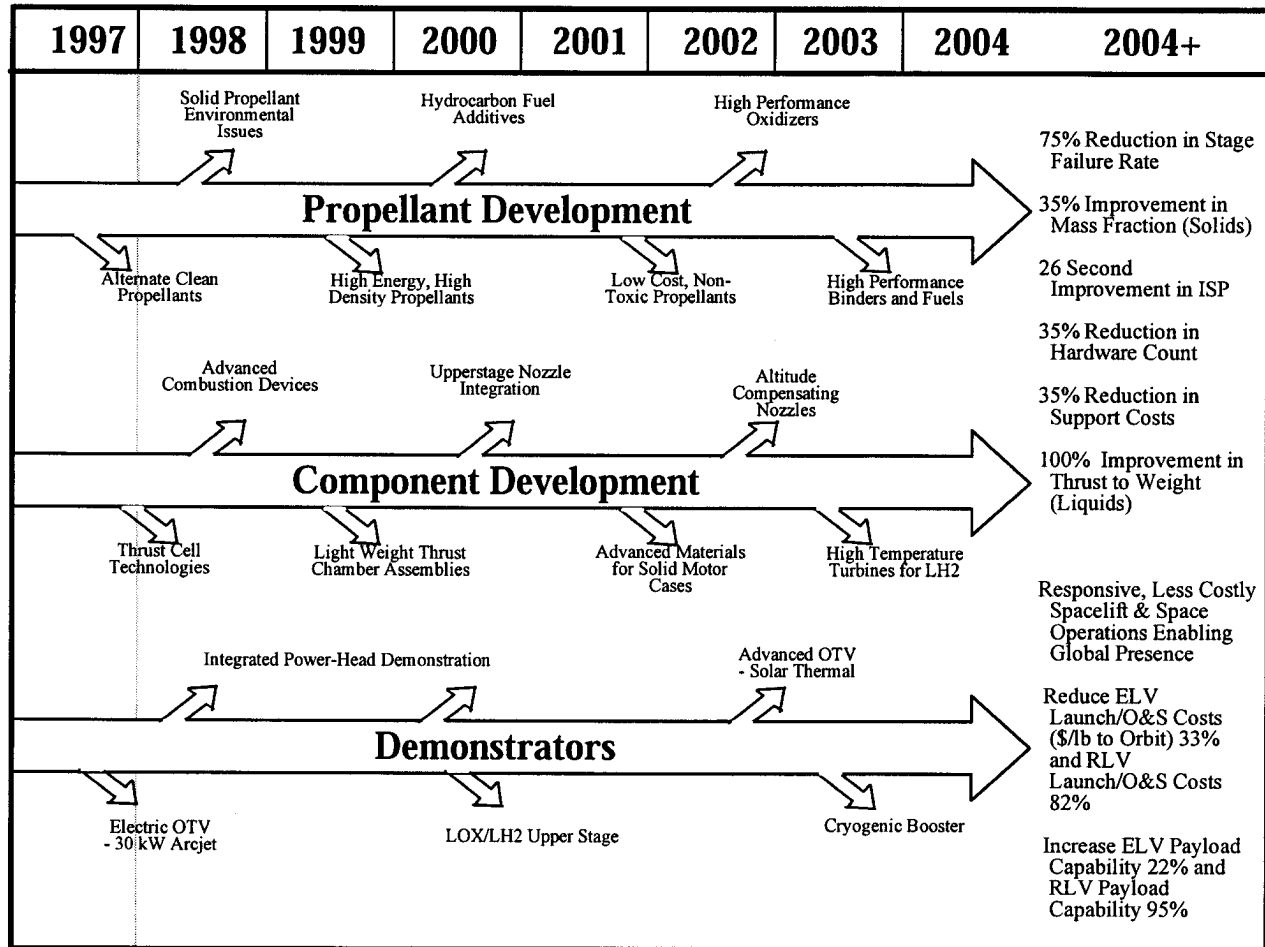
These technologies will provide the technical solutions to develop next generation space systems in addition to upgrades for existing space vehicles. The major challenges to achieving the spacelift goals are addressed by our IHDRPT programs, which coordinate our efforts closely with the Air Force, Navy, Army, NASA, and Industry to lower development costs for everyone involved.

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### MAJOR ACCOMPLISHMENTS

A series of U.S. Patents were issued pertaining to an entirely new polymer technology that was pioneered and developed at the Phillips Laboratory Propulsion Directorate. The hybrid polymer technology is being evaluated along with conventional (wholly organic) high performance plastics as engine ducting, trusses, component substructures, cases, and thermal insulation applications in both rockets and space vehicles.

A small Solid Oxygen (SOX) Engine was developed and fired by the Phillips Laboratory. The objective of this project was to demonstrate that cryogenic solids can be burned in a hybrid rocket geometry. Solidifying the oxygen increases the oxi-



dizer density and provides a means of storing other energetic oxidizers, such as ozone. It has been calculated that adding 50% ozone in solid oxygen will increase the Isp of a hydrogen-solid oxygen/ozone system by 20 sec.

Phillips Laboratory tested an advanced hybrid rocket fuel demonstrating that high regression rates are possible in a hybrid tactical rocket engine. It also demonstrated that the fuel's regression rate is dependent on the mass flow of the oxidizer rather than pressure as is the case with solid rocket motors. PL also tested an oxidizer for hybrid tactical rockets.

This was the first firing using Hydroxyl Ammonium Nitrate (HAN) and demonstrated the application of HAN as a potential hybrid tactical oxidizer.

### CHANGES FROM LAST YEAR

Strategic sustainment was added to the Boost and Orbit Transfer Propulsion Technology thrust this year. This effort will look at technologies to upgrade and maintain the U.S. strategic missile fleet as well as transition the technologies into current and future launch vehicles.

Milestones	Year	Metrics
Demonstrate alternative oxidizers for advanced solid propellant technology	FY98	Demonstrate solid propellant with theoreticalsp greater than 267.5 sec
Demonstrate split lineflexseal nozzle at sea level	FY98	Show 2% increase in mass fraction and 2% increase in Isp
Demonstrate 1200psi expander cycle LOX/LH2 upper stage engine	FY99	Demonstrate IHPRPTPhase I goals for upper stage
Develop/test high performance solid motor case	FY99	Show 10% reduction in component weight and 15% reduction in component cost
Demo integratedpowerhead (IPD) preburner/turbomachinery	FY99	Test IPD engine conditions. Quantify performance, operability, and reliability improvements
Develop/test altitude compensating nozzle design	FY00	Show 5-10% increase in flight trajectory performance

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## THRUST 2: SPACECRAFT AND TACTICAL PROPULSION TECHNOLOGY

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### USER NEEDS

The Air Force Policy of "Global Presence" cites Situational Awareness, Strategic Agility and Lethality as tenants needing "technological innovations" to "enhance US ability to exert presence." The following SMC/AFSPC, ACC and NASA Development Plans require propulsion improvements to fulfill critical deficiencies:

**Missile Offense, Air to Surface, and Counterair:** Motor Service Life Prediction and Extension, High Performance Environmentally Acceptable Propellants, Low Cost Environmentally Acceptable Manufacturing Processes

**Conventional Deterrence:** Missile Propulsion Material Applications, Global Range and Survivability, Missile Propulsion Technology, Missile Propellant Non-Destructive Test Technology, Solid Rocket Motor Manufacturing, Reliability

**Reconnaissance/Surveillance:** Cost and Survivability, Prompt Response without Force Deployment, Long Range Strike Capability

**Counterspace, Missile Warning:** Survivability

**Missile Defense:** Survivability, Propellant Development

**Non-Space:** Fast Reaction Tactical Missiles, Less Time to Target, Increased Range, Throttle on Demand, Low Cost, Increased Environmental Compliance.

**Satellite:** Advanced Propulsion/Power Conversion for Electric Propulsion (for Stationkeeping/Maneuvering)

**Weather:** Small Satellite Technology

**Navigation:** Modernization of Current Systems, Upgraded Future Systems to Replace Current Systems with Lower Power Consumption, Improved Power Conversion, Advanced Attitude Control, Advanced Electric Propulsion and Solar Propulsion.

### GOALS

The propulsion needs identified above will be fulfilled by achieving the goals set forth in the Integrated High Payoff Rocket Propulsion Technology (IHRPT) initiative. IHRPT's vision is to double solid rocket propulsion capability by 2010 through the development of advanced, innovative rocket propulsion technology

By 2000, satellite propulsion systems will:

- extend their life in geosynchronous orbit (GEO) by 25%
- double repositioning capabilities (number of repositioning maneuvers) or

- increase allowable satellite mass by 10% with present life span capabilities.

By 2010, satellite propulsion systems will:

- extend their life in GEO by 45%
- increase repositioning capability by 5 times or
- increase allowable satellite mass by 30% with present life span capabilities.

By 2000, the IHRPT tactical goals will:

- increase either warhead payload or range by 10%.
- The number of theater missile defense systems to cover an area can be reduced by 26% for divert (steering control) propulsion systems.

By 2010, the IHRPT tactical goals will:

- double tactical warhead payload or range and,
- reduce necessary theater missile defense systems for divert propulsion by 60%.

Solar electric and solar thermal spacecraft propulsion development is critical to achieve the satellite improvements for stationkeeping and maneuvering. PL develops spacecraft propulsion technology for:

- pulsed plasma thrusters,
- anode layer thrusters, and
- solar thermal (laser thermal) systems.

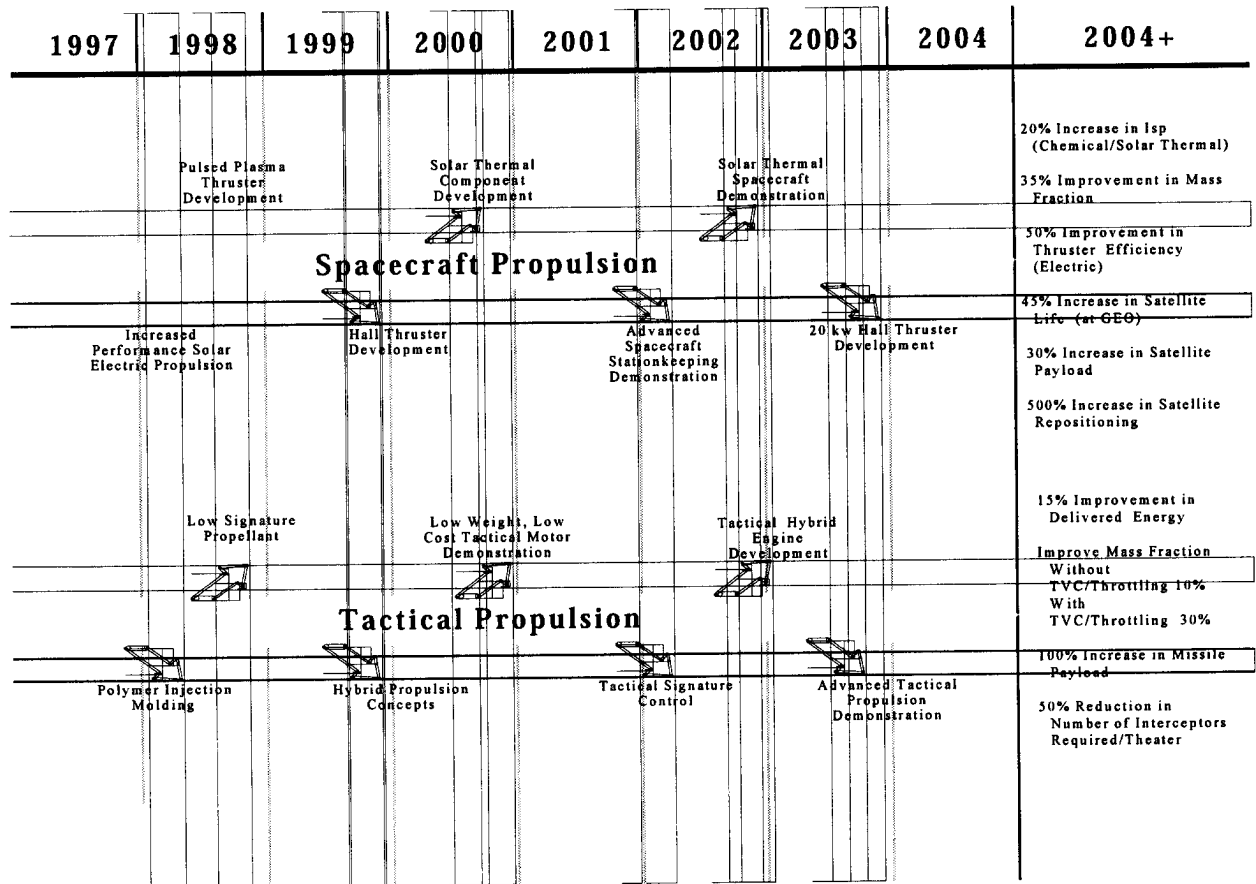
To accomplish the tactical payoffs, solid propellant and motor component development is crucial. The PL rocket propulsion directorate has the only programs that develop solid rocket propulsion technology for all Air Force tactical missile systems. PL develops tactical propulsion technology for:

- developing low signature, high performance propellants to eliminate tactical missile vulnerability caused by signature detection.
- developing lightweight, tactical components to allow for increased warhead carriage capability or increased range.
- developing longer life, stronger motor components.
- decreasing production time and costs by utilizing our carbon densification techniques and lightweight coatings.
- decreasing nozzle erosion rates (which increases reliability, performance, and range)
- increasing oxidation resistance (which also increases reliability).

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### MAJOR ACCOMPLISHMENTS

PL researchers have discovered and characterized one of the major sources of the low pulsed plasma thruster (PPT) thrust efficiency - severe propellant loss mechanisms. This new understanding has fueled the design of advanced PPTs, presently being tested



at the PL Electric Propulsion Laboratory, which are expected to have thrust efficiencies over three times higher than present designs.

Two experimental PPTs, designed by PL researchers and fabricated at the Propulsion Directorate, have passed their initial functional tests. The PPT's include the smallest electric propulsion thruster ever fabricated and tested.

PL, in cooperation with contractors, developed a new way to design and fabricate spray foam-rigidized solar concentrators. The foam material and solvent are sprayed onto the back of the reflector within a conical shield so they would not contribute

to the space debris problem. It would cure in UV, then the shield and front canopy could be stripped away leaving the rigid shell that would only dimple around areas of micrometeoroid or space debris penetration.

### CHANGES FROM LAST YEAR

The goals for the spacecraft subthrust have been refined. This does not impact any of the long term payoffs for the subthrust.

Milestones	Year	Metrics
Design tactical hybrid rocket engine	FY98	Demonstrate 5% increase in mass fraction and 7% increase in delivered energy
Develop and integrate hardware for advanced tactical propulsion demonstrator	FY98	Demonstrate 10% increase in mass fraction and 7% increase in delivered energy
Fabricate high altitude balloon experiment for improved solar thruster	FY99	Demonstrate 10% increase in Isp and 15% increase in mass fraction
Develop/test pulsed plasma thruster	FY00	Increase MightSat flight capabilities by increasing Isp by 25% and increasing thruster efficiency by 25%
Develop anode layer thruster (ALT)	FY00	Demonstrate 15% increase in mass fraction and 15% increase in thruster efficiency



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## THRUST 3: SPACE VEHICLE TECHNOLOGIES

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The Space Vehicles Technology Thrust supports the successful accomplishment of satellite and launch vehicle missions by conceptualizing, developing, and demonstrating pervasive technologies that enable the use of the most effective payload packages, operating in the optimum environment. This thrust encompasses a wide range of disciplines including structures and controls, thermal management, and electrical power systems. Whether future systems are large, high power communications or weapons platforms, or small, distributed surveillance packages, technologies are being developed to reduce weight, reduce costs, and increase the capabilities of space systems. The ultimate aim is a massless, rigid spacecraft bus with limitless power generation and energy transmission capabilities that provides the optimum structural and thermal environment and that costs next to nothing.

The Space Vehicle Technologies Thrust has three subthrusts: Dynamic Systems, Structural Systems, and Space Power.

The focus of the Dynamic Systems subthrust is providing vibration control, precision mechanisms, and cryocoolers that enhance the performance of payloads. Key programs in this area include launch load vibration and acoustic attenuation, 35/60K multistage cryocoolers, and high precision, low-shock deployment devices.

The primary objectives of the Structural Systems subthrust are reduced mass and manufacturing costs. Key programs include multifunctional structures, advanced composite structures, inflatable structures, and large array antennas. Additionally, the thermal bus focused technology area seeks to provide large heat transport capabilities utilizing loop heat pipes and integrated capillary pumped loop systems.

The Space Power subthrust is investigating new ways to generate, store, and distribute power efficiently and in quantities required by future spacecraft subsystems. Key programs in this area are Alkali Metal Thermal Electric Conversion (AMTEC), the flywheel energy storage and attitude control cooperative effort with NASA/LeRC, and the Multijunction Photovoltaic Array ManTech program.

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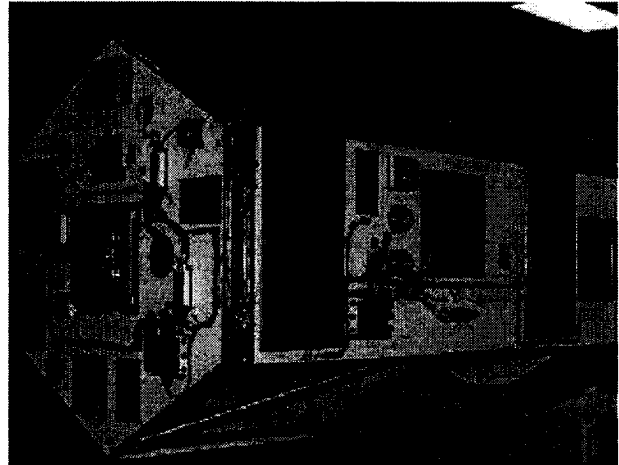
### USER NEEDS

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The technologies developed in this thrust support many SMC programs, AFSPC Mission Area Plan deficiencies, and other Air Force space requirements. These include the following Mission and Functional Area Plans.

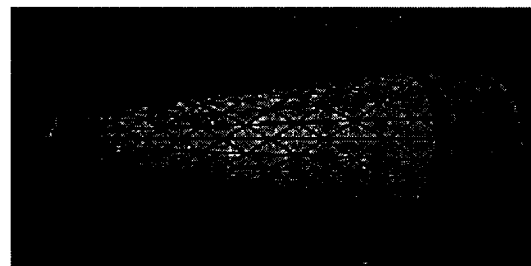
**Space Control:** The space surveillance submission area seeks to monitor activities in the near earth corridor. To this end, acquisition, tracking and pointing precision structures, very low temperature cryocoolers for broadband IR sensors, and high efficiency power generation are required. The national missile defense submission

area has identified the need for beam generator isolation from expansion and pointing optics



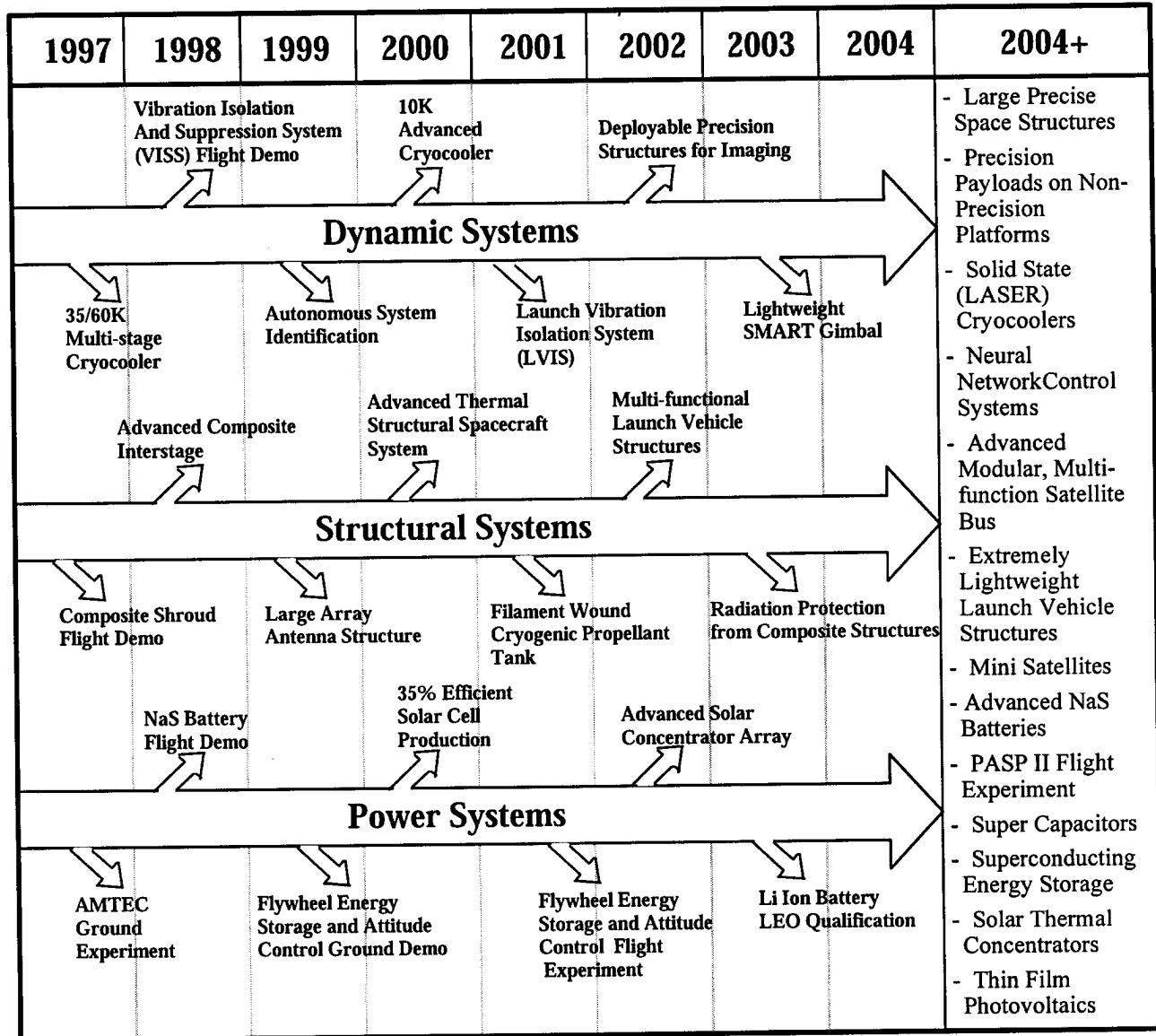
*APEX Spacecraft with Photovoltaic Array Solar Power (PASP) Plus Diagnostics Experiment*

**Space Force Enhancement:** The surveillance and threat warning submission requires the ability to loiter in low earth orbit (LEO), monitor hostile activities on the earth surface, and communicate a warning. Cryogenic Coolers for 60-150K IR sensors, lightweight structures and antennas, operable smart structures, and high cycle energy storage systems are required to enable this mission. The navigation submission area has identified the need for lightweight, low cost arrays, while the environmental monitoring submission area requires lightweight antennas and cryocoolers for the appropriate range of IR sensors. For the communications submission area, lightweight antennas, high efficiency power generation and distribution, and an advanced thermal management bus are being developed.



*Composite Shroud Winding Tool*

**Precision Employment:** The global prompt strike submission area will employ weapon systems requiring large capacity cryogenic coolers, high efficiency power generation, and large, lightweight precise structures.



**Space Support:** The launch operations submission area has identified deficiencies for multi-use upper stage primary batteries, effective launch vehicle isolation systems, and strong, lightweight launch vehicle structures.

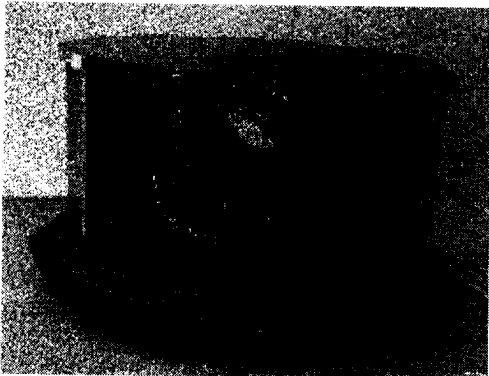
### GOALS

For the three subthrusters which comprise the Space Vehicle Technologies thrust, the near term goals for 2000 include the following:

- Develop cryocoolers capable of operating in the 10K-180K range with a 5 year operational lifetime
- Develop and demonstrate cryogenic thermal control system integration technologies that eliminate significant induced vibration (0.1 Nrms)
- Produce Cryocoolers with reduced power consumption (50 W/W<sub>COOLING</sub>) and specific mass (8 kg/W<sub>COOLING</sub>)

- Decrease dynamic launch loads to which a satellite is subjected by a factor of 5
  - Reduce pyrotechnic shock to which satellites are subjected by more than two orders of magnitude
  - Decrease on-orbit disturbances experienced by payloads by a factor of 10
  - Improve total system power performance to 8 W/kg
  - Reduce Power System Costs to \$6,000/W
  - Improve Solar Cell Conversion Efficiency to 25%
  - Develop Advanced lightweight and concentrator arrays with specific power of 100 W/kg
  - Reduce satellite structural mass by 40% and reduce cost by more than 10%
  - Reduce launch vehicle structural subsystem cost by 25%
- The far term goals for 2010 include the following:
- Develop cryocoolers capable of operating in the 10K-180K range with a 10 year operational lifetime

- Develop and demonstrate cryogenic thermal control system integration technologies that eliminate significant induced vibration (0.001 Nrms)
- Produce Cryocoolers with reduced power consumption (30 W/W<sub>COOLING</sub>) and specific mass (3 kg/W<sub>COOLING</sub>)
- Decrease dynamic launch loads to which a is subjected by a factor of 20
- Decrease on-orbit disturbances experienced by payloads by a factor of 100
- Improve total system power performance to 15 W/kg
- Reduce Power System Costs to \$ 3,000/W
- Improve Solar Cell Conversion Efficiency to 35%
- Develop Advanced lightweight and concentrator arrays with specific power of 150 W/kg
- Reduce satellite structural mass by 75% and reduce cost by more than 25%
- Reduce launch vehicle structural subsystem cost by a factor of 10



*Advanced Spacecraft Structures Research Experiment (ASSTREX)*

- Demonstrated applicability of electron-beam processing for fabrication of composite space structures.
- Commenced characterization of 5 W Reverse Brayton Cycle Cryocooler
- Demonstrated feasibility of Multi-Stage Multi-Load 35/60K cryocoolers for MLIR/LWIR Sensors.
- Successful flight Demo of highest ever operating temperature liquid metal heat pipe on STS-77.
- Accomplished 40% improvement in heat transport with 1.45 micron metal wick capillary pumped loop.
- Proved feasibility of employing precision payload packages on non-precision satellites with active vibration isolation system (VISS).
- The structures and control technology area received a score of two with special mention from the SAB Review Board.

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### CHANGES FROM LAST YEAR

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- Thrust 3 Structural Systems and Thrust 5 Power and Thermal Management from the previous TAP have been combined into Thrust 3 Space Vehicle Technologies of the current TAP. This combination of technologies creates a synergy that will accelerate realization of a truly modular, multifunctional satellite bus.
- Flywheel energy storage and attitude control joint program with NASA initiated.
- Modified AMTEC program to support NASA/DOE advanced radioisotope program.
- Thermal Management (Bus) focused technology area integrated with spacecraft structures technologies branch.
- Launch isolation technology has changed from a PL push to an SMC/TE sponsored program.

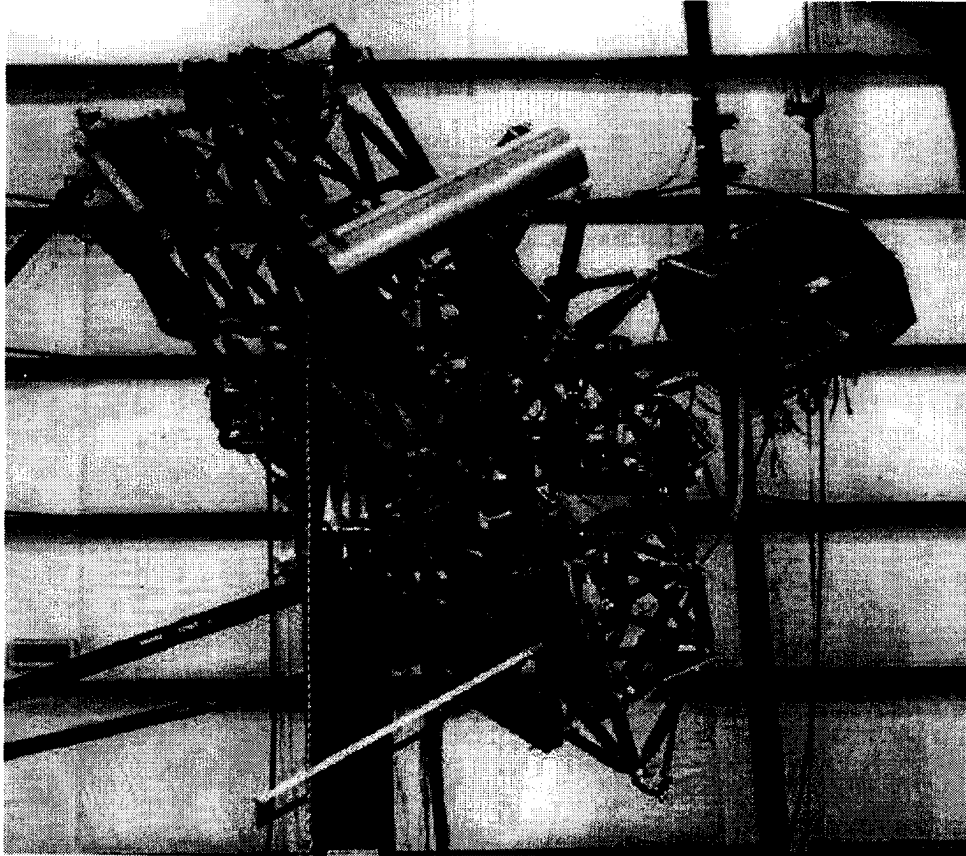
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### MAJOR ACCOMPLISHMENTS

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- Completed sodium sulfur flight test safety reviews successfully.
- Provided key data to NASA/DOE that enabled them to select AMTEC as the baseline converter for their advanced radioisotope power system. Successfully tested the first multi-tube AMTEC cells in vacuum.
- Initiated flywheel energy storage and attitude control program in conjunction with NASA.
- Accepted delivery of 150 24% efficient multijunction solar cells.
- Delivered advanced lightweight composite bus structures for BMDO STRV-2 and PL MightySat-I vehicles. Demonstrated 11% structural mass fraction and reduced fabrication time by 30%.

MILESTONES	YEAR	METRICS
Next Generation Multifunction Structure S/C PDR	FY98	Reduced mass by 4X; Fully integrated
STRV -2 launch with VISS on-orbit demo	FY98	Demonstrate precision platform on noisy bus
Flight test AMTEC cells	FY98	>30% efficient conversion
Qualify and flighttest NaS battery	FY98	Tech transition 100 Whr/kg NaS cells with 10 year life cycle
Begin development of advanced concentrator arrays	FY98	Demonstrate modular, integrated solar cell/battery/PMAD system
Develop and breadboard high voltage PMAD technology	FY98	Demonstrate 100v, 90% efficiency PMAD components
Demonstrate large capacity Li Ion battery technology	FY98	Light weight energy storage technology > 40hr
10 K cryocooler report	FY98	Demonstrate feasibility of 10 K system
35K/60K advanced Stirling cryocooler	FY98	Multi stage, multi load protoflight cryocooler demonstrated
Ground test flywheel energy storage system	FY99	Light weight, high cycle life energy storage technology > 40hr
Transition multi-junction cell technology from ManTech to industry	FY99	Mass produce cells with efficiencies 24-26%



*Precision Structure Controls Experiment*

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## THRUST 4: ADVANCED SPACE TECHNOLOGY INTEGRATION AND DEMONSTRATION

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### USER NEEDS

In order to continue to effectively control and exploit space into the next millennium, the Air Force must continue to field affordable, technologically superior systems and effectively use cutting-edge technology to improve operational tactics. Technologies focused on meeting USAF operational needs and deficiencies are identified through the use of the Air Force Technology Planning Integrated Product Teams (TPIPTs); however, timely transition of those technologies has often proven difficult. Orderly and routine demonstrations provide flight heritage for emerging technologies and are effective platforms for the development and demonstration of improved operational tactics. Within this thrust PL conducts regularly-scheduled space, near-space, re-entry from space, and ground demonstrations to facilitate risk reduction and technology maturation, and hasten technology transition to the operational user. These demonstrations include combining new technologies into mission oriented demonstrations to show advances in operations and tactics. The synergistic effect of operations, tactics, and new technologies will maximize operational system improvements in the areas of life cycle costs as well as performance.

### GOALS

The broad goals of the Advanced Space Technology Integration and Demonstration Thrust are to transition technology by:

- Providing integrated space technology flight and ground demonstrations to address AFSPC identified deficiencies and requirements, as well as DDR&E Defense Technology Objectives
- Reducing cost of developing, launching, and operating space systems;
- Minimizing risk associated with inserting advanced technology into operational satellites developed by SMC and operated by AFSPC.
- Developing technology advances to sustain and increase the key ICBM strategic and tactical capabilities, which include range instrumentation and safety, flight and terminal navigation accuracy, as well as lowering the life cycle cost of the existing ICBM fleet.

Methods to Meet Goals:

- Validate new satellite technologies using state-of-the-art and standard satellite configurations;
- Plan and execute advanced technology and integrated space flight demonstrations with the user, including development of new operational strategies based on advanced technology;

- Leverage civil and commercial spare capabilities to examine new space technologies while reducing budget/schedule requirements.
- Employ simplified command and control concepts;
- Employ increased autonomous satellite operations;
- Verify the maturity of technology, and transition them
- Emphasize a streamlined concept of operations with maximum use of experienced integrated product teams including contractors, in-house expertise from the AF Laboratories, and other government agencies;
- Lead the improvement of the laboratory's integration and system engineering capability;
- Provide actual experience in design, fabrication, integration, systems engineering, and flight of spacecraft payloads to laboratory personnel;
- Integrate and execute ground, near space, and space demonstrations for other DoD agencies leveraging their technologies to enhance AF capabilities;
- Demonstrate GPS Range Standardization/Safety Tech;
- Demonstrate new miniature GPS systems to lower range costs and enhance safety with greater accuracy and reliability;
- Demonstrate GPS accuracy enhancements and anti-jam antennas and systems;
- Increase cost effectiveness, missile navigation, and testing accuracy with improved GPS/INS coupling;
- Fly the Missile Technology Demonstration III (MTD III) during FY98 to gain data on a high speed instrumented penetrator warhead and GPS/INS navigation system.

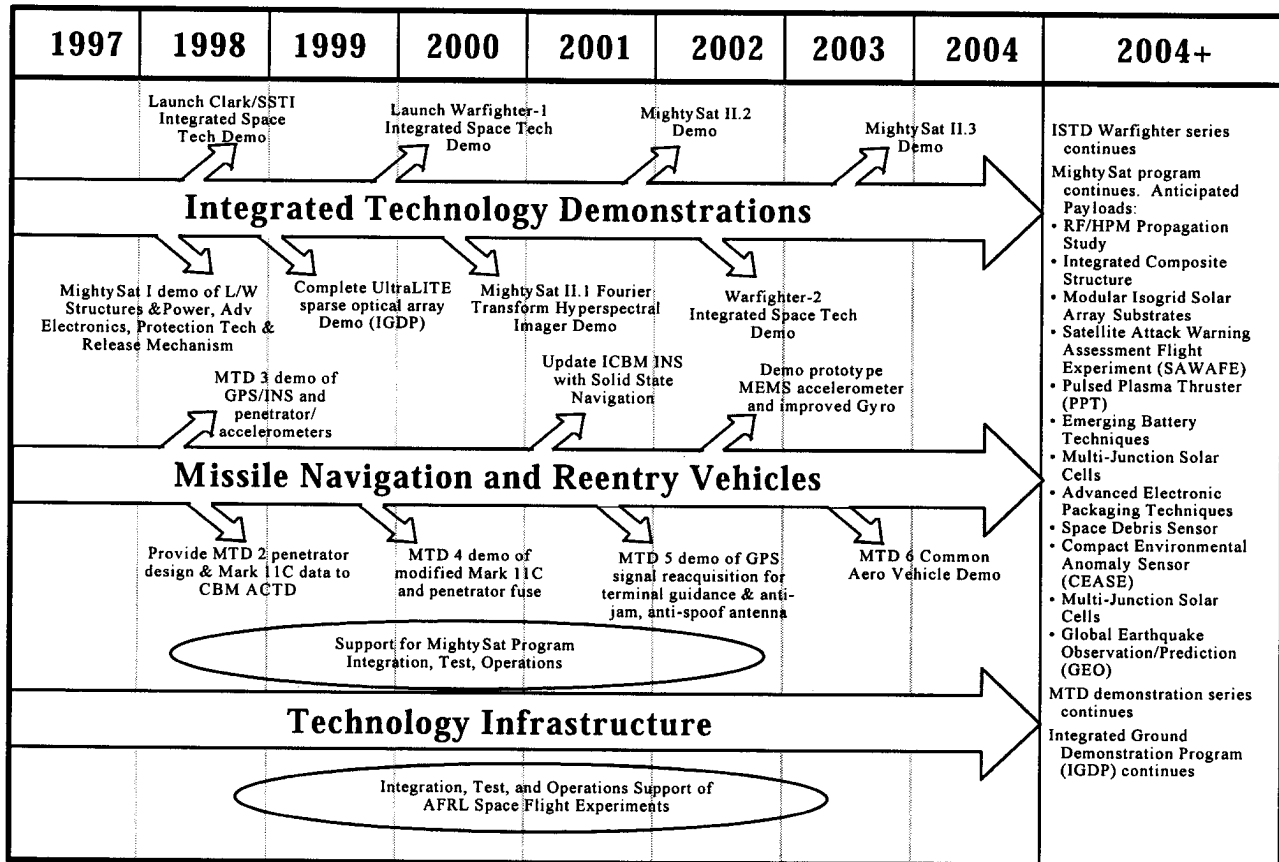
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### MAJOR ACCOMPLISHMENTS



*MightySat I Satellite Integration*

MightySat I was delivered to PL in November 1996. MightySat I has completed all experiment and payload



integration at the Phillips Laboratory's Aerospace Engineering Facility (AEF) as well as having completed vibration, thermal-vacuum environmental, and mission sequence testing. The satellite will test a composite structure, high efficiency solar cells, a microelectromechanical accelerometer, high density rad-resistant microelectronics, a shape memory actuator device, and a micrometeor particle impact device. MightySat I This is significant because this is the first PL satellite to have completed test and integration at the AEF.



*ITSD Clark Van*

The Integrated Space Technology Demonstration (ISTD) Clark project took delivery of their Mobile

Ground Station early in FY97. The Clark van was soon pressed into use for the Army's Roving Sands exercise. The exercise covered territory in parts of New Mexico and Texas, and involved the world's largest demonstration of military equipment and personnel. The Clark van was used to provide simulated space-based sensor data to field commanders during the exercise. These sensor collections were used by the US Army to aid in intelligence preparation of the battlefield. The Clark van's participation in the Roving Sands exercise was specifically tailored to the Army Air Missile Defense Command for the Theater Missile Defense (TMD) Tactical Operations Center (TOC). The NASA Clark satellite will launch in FY98 and downlink multispectral imagery data directly to the Clark van.

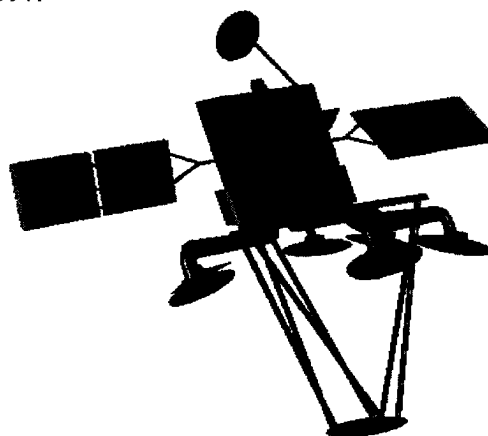
The Missile Technology Demonstration 2 (MTD 2) test flight was conducted on 29 January 1997. The first flight, MTD 1, on 16 August 1995 demonstrated the use of a commercially available, differential GPS/INS package that gave extremely accurate range metrics and position information to within 3.2 m at impact and enabled the impact point to be estimated continuously for an on-board autonomous range safety solution.

MTD 2 consisted of a modified Pershing II reentry vehicle on top of a SR-19 rocket motor booster. The SR-19 is the second stage of the Minuteman II. The active on-board differential GPS/IMU provided the navigation for the flight in addition to the range safety metrics demon-

strated on the first flight. Three GPS/INS packages were independently demonstrated on the flight. The missile became unstable 26 seconds into the flight when all the hydraulic fluid used to control the rocket motor nozzle was prematurely expended. The factors leading to this control instability have been determined and corrected for any potential future flights using similar systems and hardware. The on-board systems using GPS completely demonstrated their potential to monitor missile motion during the erratic flight until the command destruct was accomplished. The 650 lb penetrator survived the free-fall back to earth and was recovered. This penetrator and its two surviving internal instrumentation packages will be reflown on a future flight.

The Integrated Ground Demonstration Program has completed their first major design review for the UltraLITE ground experiment. UltraLITE will demonstrate at a system level, deployment repeatability and structural stability of a full scale sparse optical array. This experiment incorporates optical wavefront measuring sensors that determine position error of a mirror mass simulator. Sparse arrays have several potential space based applications.

This year, flight demonstrations formerly listed under Thrust 8, "Space Vehicle and Missile Dynamics Technology, have been incorporated into this thrust within SubThrust 4D, Missile Navigation and Reentry Vehicles. This includes the Missile Technology Demonstrator (MTD) series, of which MTD-2 was flown in January 1997.



*UltraLITE Sparse Optical Array Concept*

## CHANGES FROM LAST YEAR

MILESTONES	YEAR	METRICS
ISTDF #1 Integration <u>Clark/SSTI Launch</u>	FY986	Launch Mission; Begin On-orbit Demo; Mission Objectives Met Design, Fabrication, Integration Complete
MightySat I mission	FY987	Launch on Space Shuttle STS-81+
UltraLITE Experiment (IGDP #1)	FY98	Complete integration, execution, and analysis of a bench top experiment demonstrating capability to field a large aperture, sparse optical array
Missile Technology Demonstration 2B (MTD2B)	FY98	Demonstrate GPS/INS for range safety, obtain penetrator data
ISTDF #2 Initiation <u>Warfighter-1 Launch</u>	FY998	Launch Mission; Begin on Orbit Demos; Mission Objectives Met Mission Defined
Miniature Sensor Technology Integration (MSTI) satellites IGDP #2 Initiation	FY99FY 95	MSTI-3 Launch. All mission objectives met. Execute systems engineering process to identify high payoff concept w/critical integration issues which will demonstrate emerging technologies
Missile Technology Demonstration 3 (MTD3)	FY99	Demonstrate modified GPS/INS navigation and penetrator fuse
Missile Technology Demonstration 4 (MTD 4)	FY99	Demonstrate modified Mark 11C
MightySat II.1 mission	FY0098	Launch on Space Shuttle or <u>Orbital/Suborbital Program</u> (OSP) Multi-Service Launch System
MightySat II.2 mission	FY010	Launch on Space Shuttle or <u>Orbital/Suborbital Program</u> (OSP) Multi-Service Launch System
Plasma/antenna Interaction Demonstration	FY01	Reacquisition of GPS signal for terminal guidance
Anti-Jam, Anti-Spoof Antenna	FY01	Ground demonstration of antenna prototype
Micromechanical Accelerometers and Improved Gyro	FY02	Demonstrate manufacturing prototype
MightySat II.3 Mission	FY03	Launch on Space Shuttle or <u>Orbital/Suborbital Program</u> (OSP) Multi-Service Launch System
Missile Technology Demonstration 4 (MTD4)	FY03	Demonstrate Common Aero Vehicle (CAV)

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## THRUST 5: SPACE MISSION TECHNOLOGIES

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### USER NEEDS

Mission Technologies include those components that perform the primary mission function of AF space systems. In most cases, those technologies are either electronics or sensors. Electronic circuits are as pervasive in space system payloads (and other parts of the satellite) as they are in everyday life while sensors are the eyes and ears of a spacecraft.

Mission Technologies play a critical role in enabling the US to prevail in space. The AF long-range vision document, "Global Engagement" states that "Global situational awareness..." such as that provided by Mission Technologies onboard surveillance and threat warning satellites "... by its very existence, gives national leaders unprecedented leverage, and therefore advantages." The extraordinary importance of Mission Technologies was recognized in a recent letter from the Undersecretary of Defense for Acquisition and Technology where he cited advanced radiation hardened (i.e., space) electronics as crucial to the DoD and, therefore, deserving focused attention. Similarly, recent DUSD-level interest in hyperspectral sensors demonstrates how important sensor technology is to DoD warfighting plans.

In recognition of the importance of Mission Technologies, AF SPOs, BMDO, and other space system developers have identified affordable, high performance, radiation hardened, space qualifiable, sensor and signal/data processing subsystems as essential space technologies for the late 1990s and beyond. For example, improved booster detection sensitivity and coverage, and worldwide detection and tracking capability for missiles and warheads are requirements identified in several AFSPC Mission Area Plans. To meet the broad range of requirements defined by these users, technologies that extend the performance of today's space sensor and electronic components must be developed and demonstrated. The focus is to support warfighters and operational users by providing Mission Technologies that are simultaneously more cost effective and higher performance.

The following paragraphs contain specific examples of the numerous technology needs identified in SMC TPIPT development plans:

**Space Surveillance** requires adaptive optics for large mirrors (MEMS), improved radiation-hardened processor, parallel processing, and decreased optical wavefront error for space-based E-O sensors.

**National Missile Defense** requires survivable high-speed anti-jam electronics, multi-sensor fusion tech-

nologies, advanced mid- and long-wavelength focal plane arrays, and multicolor focal plane arrays.

**Surveillance and Threat Warning** mission area requires high density electronics, radiation tolerant electronics, phenomenology of radar targets and clutter, advanced low power electronics, phased array techniques, advanced space processors, survivable high-speed communications, RF sensor model/simulation tools, high performance passive sensors, improved E-O sensors, optical wavefront sensors and correctors, and hyperspectral sensors.

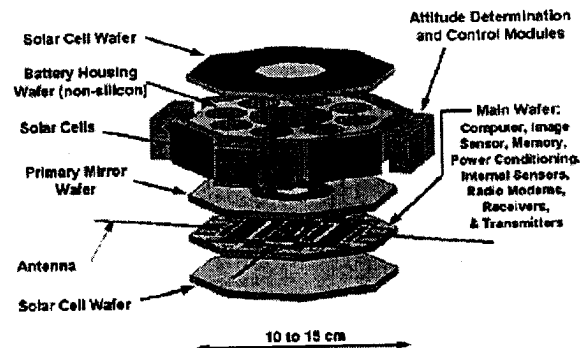
**Space Force Application** mission area requires advanced electronics, hardened electronics, processing and anti-jam electronics, thrust axis accelerometer, next generation guidance systems & technology, miniature subsystem packaging, and a low cost star sensor.

**Navigation** requires high-speed, low-power application specific integrated circuits (ASICs).

**Satellite Communication** requires higher-throughput hardened processors, and lightweight bus technologies.

**Satellite Control Network** requires distributed processing, and satellite autonomy.

**Weather** requires nanosatellite technologies.



Example of a Nanosatellite 10 - 15 cm in Diameter

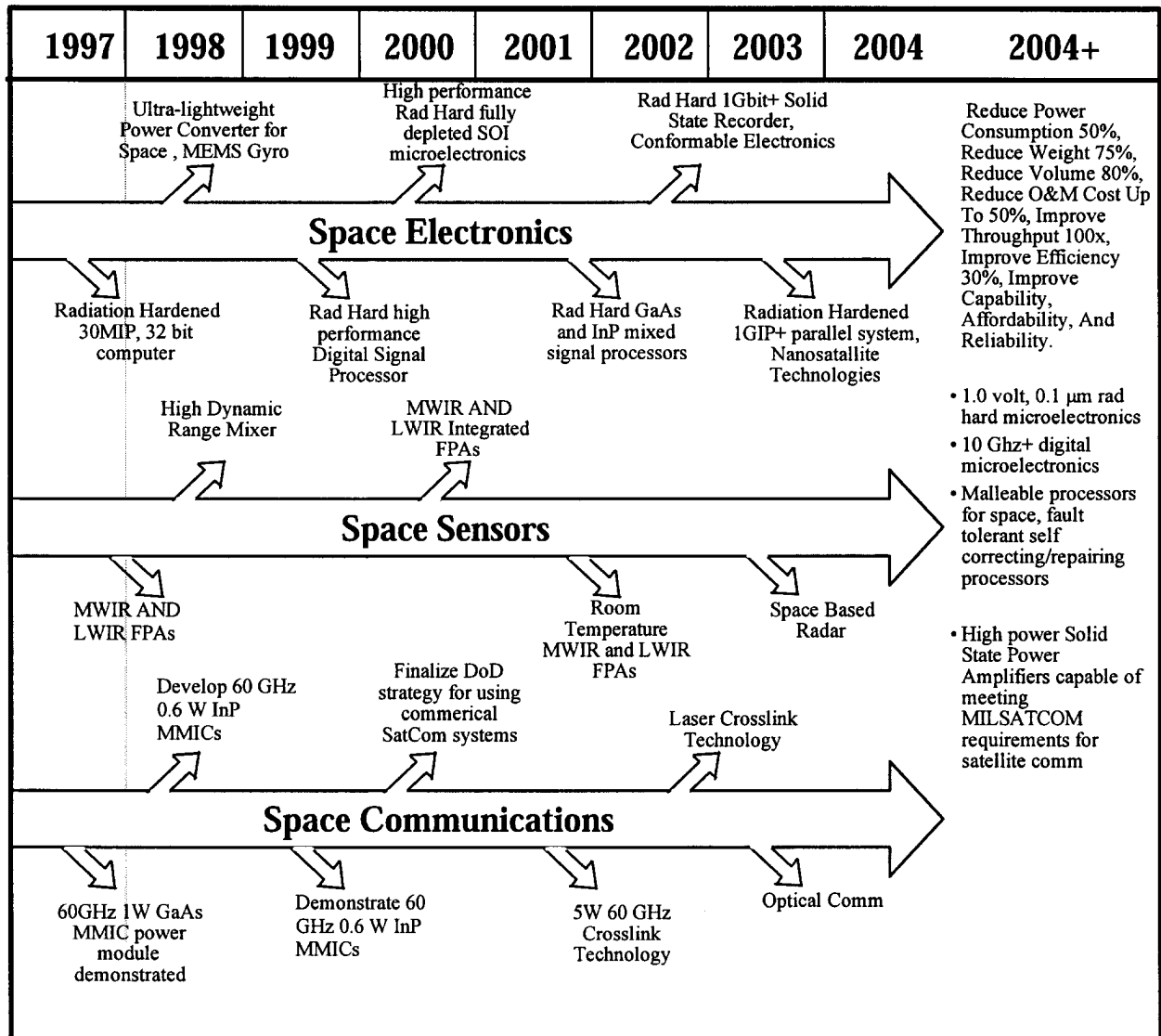
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### GOALS

**Active Sensors:** The goal is to develop Space Based Radar (SBR) technologies to enable transitioning intelligence, surveillance, and reconnaissance missions such as AWACS and JSTARS into space. This effort encompasses the antenna architectures, phenomenology, and signal processing required to develop a sensor suite for SBR. This goal will be achieved by developing:

- A sensor-level model in the "virtual satellite" model developed by the System Technologies Division.
- ♦ Extend the outputs to estimate cost and performance, and integrate with SMC and SWC battle lab models and simulations





- Sensor characterization modeling and simulation capabilities, including a radar clutter database, for selecting sensor suites and components, and for providing a system perspective for technology development
- Antenna deformation compensation and beam steering algorithms and adaptive processing techniques based on RL STAP specific-function applications
- Low cost characterization of SBR components to support antenna and other component development
- Advanced Onboard Processing & Control technologies for data reduction; advanced signal processing, automatic target recognition, sensor fusion, and cross cueing to ensure timely delivery of reconnaissance and surveillance products to the tactical war-fighter
- Large, lightweight, multi-mode/band antennas for space based military reconnaissance and surveillance missions and commercial dual-use applications

**Passive Sensors:** The goal is to reduce development costs, weight, and power consumption; increase reliability,

sensitivity, and resolution; and enhance affordability. This goal will be achieved by developing:

- Next generation, highly sensitive detectors to provide reliable missile warning by detection of dim targets, increased detection range, and improved clutter suppression
- Multicolor detectors that simplify sensor design resulting in significantly lower power requirements and lower weight
- Low power infrared detector readout electronics to reduce sensor spacecraft power requirements by more than half and radiator weight by hundreds of pounds

**Space Communication:** The goals are to develop:

- Advanced EHF communications components for satellite communication subsystems and RF crosslinks
- Ways to use commercial services to support the deficiency in mobile services
- Optical techniques for satellite communications

**Space Electronics:** The goals are to permit increased space system affordability, reliability, operability, and autonomy by developing high-performance low-cost

space electronics that satisfy customer requirements. These goals will be achieved by:

- Developing and demonstrating essential DoD space electronics (e.g., 32-bit processors, or memory) with "spin-off" use by NASA and commercial programs
- Improving direct information transmission to field commanders by 100% and reduce integration time 50% through advanced electronics (e.g., signal processing systems)

Key developments to meet the above goals are to:

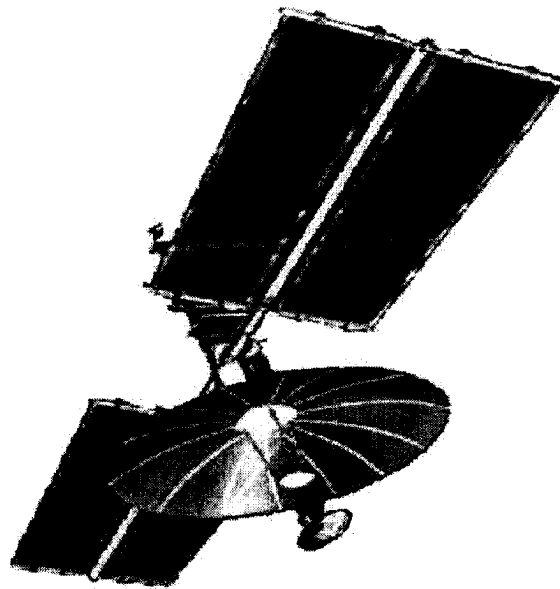
- Providing at least a 10X improvement in AF space electronic system capability in the next five years by:
  - ◆ Leveraging from the rapid progress being made in the commercial electronics industry
  - ◆ Transitioning high-demand commercial components into space qualifiable versions
  - ◆ Leveraging industry's huge investment in design, software, and testability
  - ◆ Developing innovative hardening technologies and transferring to industry
  - ◆ Building standardized space data acquisition and signal processing modules by standardizing hardened implementations of selected commercial processors
  - ◆ Demonstrating space qualifiable versions of commercial high speed data busses including the FDDI and the ATM
- Developing new computer architectures and standards to reduce the customer's cost to develop and test systems by up to 50%
- Providing more affordable computing solutions by enabling scalable processing architecture and distributed computing
- Developing Microelectromechanical System (MEMS) components to reduce the weight, size, power requirements and heat load of satellites, enabling more functional, and autonomous large satellites, and also new classes of micro- and nano-satellites

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## MAJOR ACCOMPLISHMENTS

**Active Sensors:** The Space Based Radar (SBR) technology area was very effective this past year. Working closely with customers and partners, the Space Electronically Agile Radar (SPEAR) X-band, space based radar concept, designed to perform Ground Moving Target Indication (GMTI) missions, Air Moving Target Indication (AMTI) missions, and Synthetic Aperture Radar (SAR) imagery, was developed and submitted to SMC. The Cooperative LEO Electronically Agile Radar (CLEAR) concept, designed to provide enhanced high resolution 3-d radar coverage for simultaneous moving target detection (AMTI & GMTI), high resolution imagery, and high resolution mapping with inexpensive, mass produced satellites, was developed and presented to AFSPC. The SBR program has also had a very effective and active integrated product team comprised of members from AF Labs, DARPA, NASA, academia, and industry. SMC transferred responsibility for the modeling and simulation of SBR to PL

**Passive Sensors:** In the area of passive (e.g., infrared or IR) sensors, a HgCdTe-based MWIR camera was developed. This camera will be used to provide data to BMDO's Advanced Sensor Technology Program (ASTP) and will be used as a testbed for experimental electronics packages and focal plane array designs. An effort to increase the operating temperature of focal plane arrays to greater than 140 degrees Kelvin was also initiated to lower the total weight of a spacecraft by reducing the need for radiative cooling. In work supported by SBIRS-High, risk reduction analysis was performed. Another HgCdTe effort demonstrated the ability to mass-produce large MWIR focal plane arrays. In the area of Quantum-Well Infrared Photodetector (QWIP) technology, a new category of dark current effects that manifest themselves at the low temperatures required for space applications were discovered, and the sources that are responsible for this noise were explained. A collaborative effort was initiated with JPL to develop a low-background QWIP Focal Plane Array and the associated electronics at Rockwell Science Center and Hughes SBRC. Another collaborative effort was initiated with the NRC of Canada to develop a two-color QWIP/LED/CCD imaging array. A novel voltage-tunable QWIP structure was developed through a contract with the University of Florida.



**Satellite Communication:** In the area of Satellite Communications, working with the MILSATCOM office, efforts were initiated to evaluate crosslink technologies for EHF payloads and satellite buses. To ensure other AF technology developments were exploited, this effort was coordinated with ongoing communication system developments at Rome Laboratory. The SBIR program was exploited to advance space communication technology. During the past year, three Phase I SBIRs were all selected for Phase II ef-

forts. The developments will include engineering and construction of a 5 Watt 60 GHz power combiner, a 28 GHz 1 Gbps wireless link system, and a Code Division Multiple Access fiber optic network that can support up to 1 Terabit/sec. Fabrication and testing of a 1-Watt 60-GHz Solid State Power Amplifier was also initiated.

**Space Electronics:** Many space electronics success were obtained this past year. In collaboration with industry a new analog-to-digital convertor (ADC) was co-developed for the GPS MAGR anti-jam filter. It is both a successful commercial product and a space-qualified component that outperforms any previously space-qualified ADC. A collaborative was initiated with NASA JPL to develop a postage-stamp sized microcontroller-based data acquisition system that offers a flexible solution for a variety of simple spacecraft processing tasks for both NASA and the AF. The controller will be used by NASA in two Mars surface probes that are under development for the Mars 98 program, and a hardened version is being evaluated for AF single-node and fault-tolerant applications. In another effort, a micro DC-DC power converter was developed--the size was reduced from 1000 in<sup>3</sup> to 2 in<sup>3</sup> and weight from 80lb to 0.25lb. Finally, development and application of the "hardening by design" approach was continued this year. "Hardening by design" was used for a control application on the STRV-1d mission. In this application, components must withstand harsh radiation in GEO-transfer environments. The approach is now being applied to advanced commercial processes, and being extended to include analog circuitry.

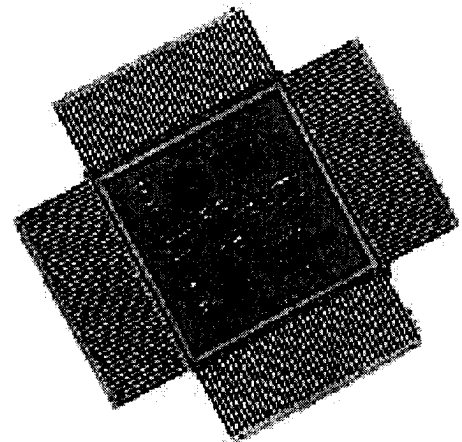
In the flagship, advanced space processor program, a single-board 32-bit ASCM (computer) was demonstrated. This led to an "Outstanding" technical CDR on SBIRS-Low. In addition, ASCM technology was selected for the GPS-IIF and SBIRS-High programs. The first light-weight, double-sided 32-bit data/signal processor was also developed using a reduced version of

ATIM that decreased the weight and size by 10X. A titanium hardened foundry was initiated. Considerable savings will result from using commercial devices for prototyping and reuse of software. Finally, the Improved Space Computer Program was initiated to satisfy space system developer needs in the FY01/03 time frame with a scaleable, integrated computer architecture.

In advanced electronics packaging, advancements were made in the state of the art in space multichip module (MCM) technologies. Twenty high-density interconnect (HDI) modules were developed for the BMDO Midcourse Sensor eXperiment (MSX) in May 1996. This represents the first fielded demo of this breakthrough packaging technology. Furthermore,

PL's advanced packaging expertise was key to successful development of the anti-jam filter for the GPS Miniature Advanced GPS Receiver (MAGR). The conceptual packaging framework is being extended from the 200X size and weight reduction reported last year to even more robust, paper-thin MCMs that can approach 1000X reductions.

In the Microelectromechanical Systems (MEMS) technology area, an effort was initiated to develop extremely small microrelays which require power only when switching. Collaborations with two other PL directorates, Space Experiments and Lasers and Imaging, to develop several micromirror systems for adaptive optics and beam steering are in place. Two space experiment payloads, referred to as Microsystems And Packaging of Low-power Electronics (MAPLE), were developed and delivered to the MightySat I and Space Test Research Vehicle programs. In MAPLE, commercial processors and MEMS devices are to be flown alongside space qualified advanced packaging and field programmable gate arrays. We have also proven the long term reliability of thermal microactuators, a concept first conceived by PL and AFIT (patent submitted) and fabricated by Sandia National Laboratories. Arrays of these actuators provide some of the highest force per area of any MEMS actuator. Initial radiation characterization on thermal actuators shows them to be immune to normal levels of space radiation.



GPS Anti-Jam Filter

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### CHANGES FROM LAST YEAR

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- Most of the MEMS programs listed above are new this year—exceptions: Phase 2 SBIR's and some micromirror work
- Space Comm budget cuts of approximately \$1M for each year in 98-03
- DIDERA modem project with Sandia National Labs has been put on hold due to funding limitations

Milestones	Year	Metrics
Complete development of a neural-net controlled micromirror-based adaptive optics demonstration for test in the Apache Point telescope, part of the VT/SX/LI collaboration	FY98	Deliver working micromirrors for insertion in the SX Smart Adaptive Optics testbed, then into the actual telescope system, followed by insertion into multiple BMD sensor systems
Deliver space-qualified Advanced Instrument Controller (AIC) modules to NASA for the Mars 98 surface probe	FY98	First space application of plastic form of HDI, which features 2X weight reduction, 8X cost reduction, and can withstand 30,000G impacts and operate down to -130deg C
Demonstrate three-dimensional micro-card cage under the Highly Integrated Packaging and Processing program	FY98	Demonstrate a generalized approach for packaging digital systems as a dense collection of multichip modules (50X density over competing implementations)
Develop beam steering mirror array for future optical sensor including satellite star, earth and sun trackers	FY98	Demo on space experiment and insert in one future space system
Develop, fabricate and test micromirror-based spatial light modulators for atmospheric and optical system aberration correction	FY98	Ground test adaptive optics based on micromirror arrays in AF telescope, and insert into one future space system, widely publish results
Space sensor clutter model database completed	FY98	Model radar clutter for comprehensive set of terrain types
Tropical Rainfall Measuring Mission is launched containing 280 HDI MCMs	FY98	First demonstration of thin-film MCMs built identically from three different vendors, 20X the capacity of modules flown on MSX
Develop usable MEMS-based IMU	FY99	Insert into nanosatellite design or fly on a NASA New Millennium spacecraft as demo for use in military component replacement programs

## THRUST 6: SPACE SYSTEM TECHNOLOGIES

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### USER NEEDS

The Air Force policy of "Global Virtual Presence" requires a broad base of technologies that efficiently service current and future satellite systems. Space System Technology programs are firmly rooted in the Operational Requirements Document AFSPC 00-94, Satellite Control, 4 Aug 95 and the Satellite Operations Mission Area Plan, 20 Nov 95. The focus is on supporting warfighters and operational users by providing cost effective, efficient satellite navigation, command and control, onboard mission data preparations/processing, precision orbit prediction, and modeling and simulation supporting technology trades and CONOPS evaluations.

**Space Information Dominance with the attendant Surveillance & Threat Warning and Battle Management, Command & Control:** These areas require high speed decision support systems, data fusion, high-speed on-board signal processing, fast target detection, identification, and targeting. High fidelity simulators and modeling of space environments are essential.

**Space Forces Support, Satellite Operations, and Satellite Operator Training:** Technical needs relate to the reduction of manpower to monitor remote tracking stations and satellite health and status.

**Space Intelligence, Surveillance & Reconnaissance missions relevant to Space Control, Space Surveillance and Special Operations Forces:** Ground control decision aids, automated ground control monitoring and autonomous spacecraft functions, and enhanced satellite navigation are required to accommodate future operations.

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### GOALS

Space System Technologies goals are:

- Develop reusable, affordable software architectures for on-board and ground station processing, precision navigation, precision orbit prediction, and space debris detection.
- Rely on others for basic software methods and tool development.
- Develop and apply software technology concepts to achieve an optimum level of satellite autonomy.
- Develop a flexible, object-oriented modeling and simulation environment that is capable of including all space assets.

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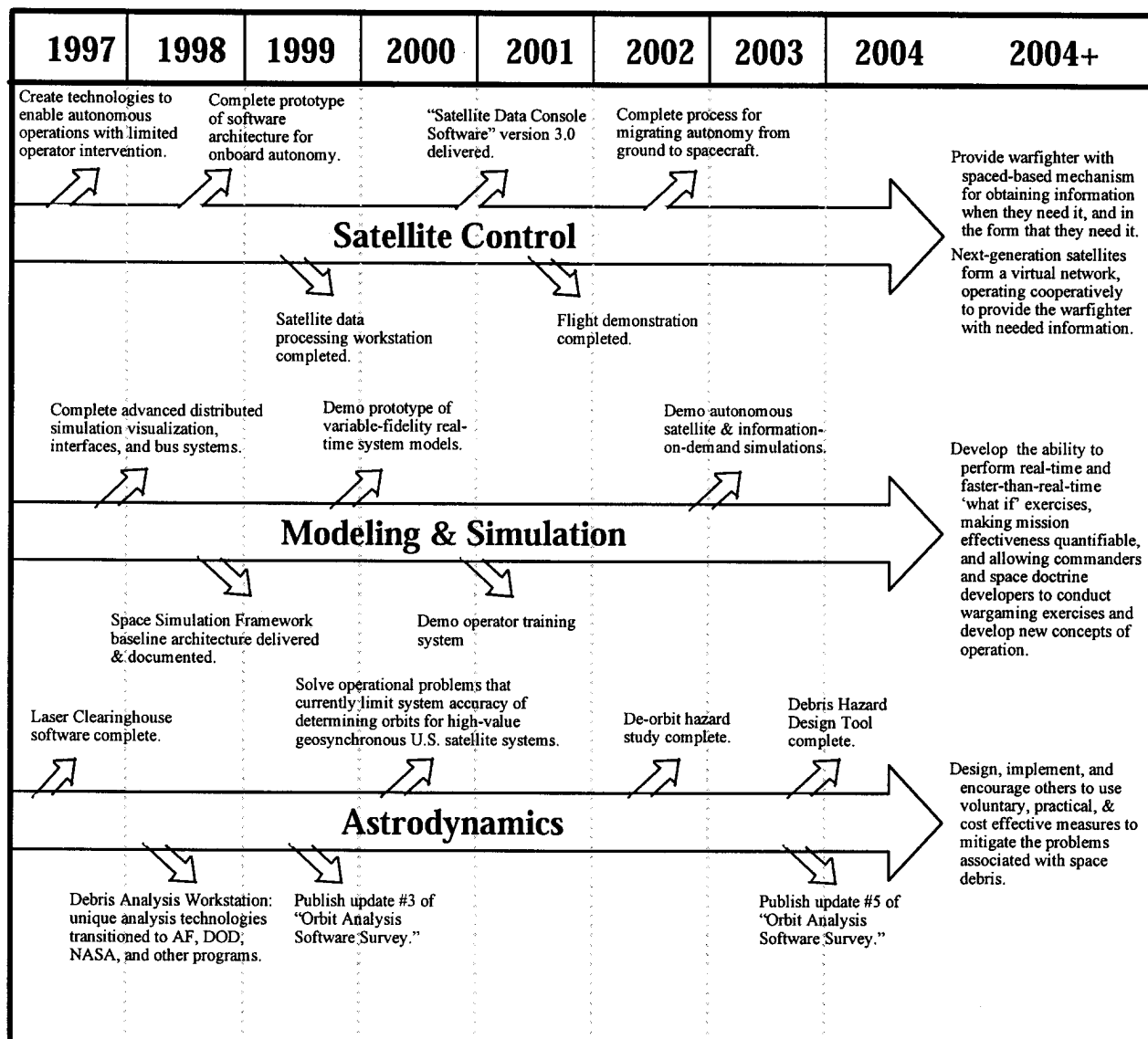
### MAJOR ACCOMPLISHMENTS

Multimission Advanced Ground Intelligent Control (MAGIC) system tracks all satellite passes at Falcon AFB Space Operations Complex (SOC) 33. This provides telemetry storage and analysis for the operational life of satellites managed by SOC 33. MAGIC also demonstrated two autonomous anomaly detection systems based on an expert and case based system. A automated pass-plan prototype and hypertext operation/training manuals were demonstrated. A low cost satellite decommutation system was demonstrated. A software architecture demonstrated the proof-of-concept that satellite software can be reused with confidence.

Achievements in FY97 for Modeling and Simulation



include contributing a Spacecraft Simulation Toolkit (SST)-based GPS simulation and a Virtual Cockpit to the ACC's Warrior Flag 97 wargame exercises. These simulations bring realistic modeling of navigational aids to the training and exercise community. Modeling and Simulation has also delivered: the SST baseline architecture; the Ultra-Lightweight Imaging Technology Experiment (Ultra-LITE) simulation; Space-Based Radar systems simulations; and limited bus health & status simulations used for satellite operator displays, anomaly resolution, and autonomous satellite operation.



Astrodynamics has set up and begun gathering data and images from its Raven telescope. This telescope is the first of its kind: a lightweight, low cost optical system designed for tracking satellites. The Debris Analysis Workstation (DAW) v. 1.0 was also delivered in 4Q97. The DAW is a state-of-the-art software tool for complex space debris hazard assessment. Astrodynamics has also published a textbook called "Fundamentals of Astrodynamics and Application." The book documents many of the fundamental routines used by astrodynamics. A unique approach blends standard theoretical derivations and explanations, realistic operational considerations, and high quality algorithms. This combination of classroom technique and actual practice is lacking in virtually all other astrodynamics engineering textbooks.

The Reusable Software Architecture for Spacecraft (RSAS) program has developed interactive software that will generate components tailored to meet a satellite's unique on-board processing requirements. This software, referred to as the "Workbench," is currently undergoing beta testing at the Phillips Laboratory and at contractor facilities. The beta workbench tailors components for a satellite's Orbit Determination (OD) subsystem. The final version will include all of Guidance, Navigation, and Control (GN&C), and parts of Electrical Power (EPDS) and Communications (COMM). Tailored components are performance requirements, design information, Ada source code, and test software. The Workbench demonstrates the concept of domain engineering. Early work in the RSAS project developed a generic model of satellite on-board processing. The satellite engineer is guided through the generic model by graphical user interfaces (GUIs). The engineer's decisions and inputs are captured in a relational database. These decisions and inputs are

eventually used to tailor generic components to meet specific requirements.

functionality and control.

The RSAS project will be completed at the end of FY97.

### **CHANGES FROM LAST YEAR**

A new effort is investigating autonomous satellite

Milestones	Year	Metrics
Develop Methods of Resolving Unknown Satellite Anomalies	FY98	Customer on-site product acceptance
Develop Debris Analysis Workstation	FY99	Predict space debris collision risk
Flight Demo of autonomous orbit control	FY01	Maintain orbit more accurately and efficiently than manual commanding

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## THRUST 7: BATTLESPACE COMMUNICATIONS AND OPERATIONS

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### USER NEEDS

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Control and exploitation of space is an Air Force mission. To achieve this goal, techniques (including sensors and operational models) are developed to specify and forecast the battlespace environment and its effects on Air Force systems and operations. Operational needs, deficiencies, operational concepts, and technology needs are defined in Mission and Functional Area Plans in several areas.

**Space-Based Weather and Environmental Monitoring** reflects that weather and environmental monitoring are backbone functions that cut across every command and military activity. All commands include weather and environmental monitoring to some extent in a variety of Mission and Functional Area Development Plans. Relevant extracts include:

**Navigation:** The Navigation Systems Modernization Plan requires increased accuracy through carrier phase ambiguity resolution, system and ionosphere range error correction, and multipath reduction algorithms for user equipment as a near-term need applicable to all GPS users. GPS systems require increased robustness against signal fades due to scintillation, especially as solar activity increases.

Improved ionospheric modeling is needed to augment GPS by using geosynchronous satellites such as Advanced MILSATCOM. Like requirements for improved GPS are also described in the Satellite Control and Intelligence, Surveillance and Reconnaissance (ISR) plans.

**Military Satellite Communications:** There is a need to extend communications coverage into the polar region, with its intense ionospheric disturbances for which no useful model yet exists. There is a requirement to combat scintillation effects associated with polar and equatorial ionospheric disturbances.

**Force Application:** There is a demand to characterize, predict, and in some cases mitigate the effects of the intense ionization that surrounds very high speed aerospace platforms. A related need is the ability for systems to receive GPS signals during periods of intense ionization.

**Satellite Control:** Critical RF communication links are susceptible to interruption by environmental disturbances triggered by anomalous solar or geomagnetic space conditions. These disturbances can increase satellite drag, alter orbits, cause high frequency (HF) blackout at high latitudes, alter the frequencies for HF communication links, and create ionospheric scintillations that disturb ultra-high frequency/extremely-high frequency (UHF-EHF) communications.

### **Battle Management Command and Control (BM/C<sup>2</sup>):**

Includes improved Over-The-Horizon (OTH) radar for early launch detection and assessment. ACC, North America Air Defense Command and US Southern Command identify OTH radar as a solution for current C<sup>3</sup>I deficiencies and state that OTH radar will be useful for counter-drug surveillance. Reliable use of OTH radar requires accurate specification and forecasting of the ionosphere, which controls OTH operational performance.

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### GOALS

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Specify and model the hazardous charged particle environment throughout near-earth space so designers can maximize performance with minimum life-cycle costs. Measure key solar and interplanetary parameters for specification and forecast models to minimize space system degradation or failure.

Obtain a global, real-time capability to accurately specify and forecast the ionosphere, and provide timely warning of when, and how severely, ionospheric disturbances will disrupt C<sup>3</sup>I systems. Assess the effect of ionospheric scintillations that degrade GPS accuracy or availability. Specify and predict the neutral density of the upper atmosphere within tolerances to meet operational requirements for satellite tracking, reentry predictions, detection of orbital changes, determination of satellite lifetimes plus on-board fuel requirements, and space debris hazard assessments.

Combine the energetic charged particle, ionospheric, and neutral density models into an Integrated Space Environment Model that monitors the environment in which space systems operate, and warns of hazards to space- and ground-based systems, like power transmission grids.

Characterize and predict the intense ionization around hypervelocity platforms, quantify their effects on GPS radio signals, and develop techniques to control ionization to alleviate radio blackout and decrease flight drag.

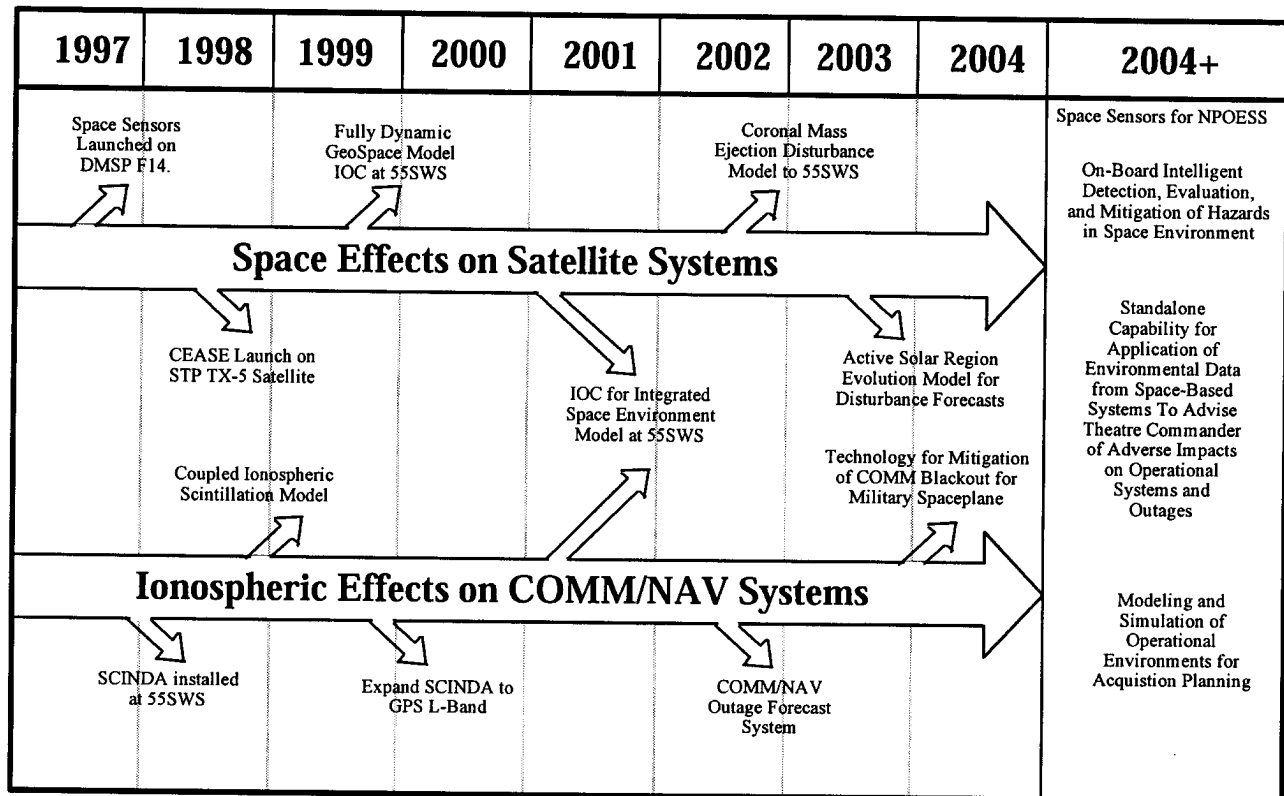
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### MAJOR ACCOMPLISHMENTS

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Assessed the over 150 million auroral electron spectra obtained with DMSP instrumentation. In addition to providing a clearer picture of particle distribution (log normal-Gaussian, population behaviors) for auroral disturbance models, the study will yield a better tool to ascertain auroral boundaries, key indicators of atmospheric, ionospheric, and magnetospheric disturbance levels.





Installed PL-GEOSpace version 1.30 at 55SWS in November. This version includes real-time monitoring of auroral boundaries and radiation belts.

CRRES data analysis led to a proton diffusion model for Earth's radiation belts to predict diffusion times from a given initial condition. This model will allow for a more accurate prediction for decay of storm-built populations.

Delivered the CRRES Heavy Ion Model of the Environment (CHIME) to the 55 SWS in January. More recently the code was provided to other DoD agencies and contractors. For a specified orbit and level of solar activity, the model predicts the cosmic ray spectra and single event upset (SEU) rate for memory devices on spacecraft.

A strong inverse correlation of solar wind speed with distance from a solar coronal hole was found. This fact will help forecast when, and with what intensity, solar disturbances will strike earth and disturb the neutral and ionized upper atmosphere (ionosphere), including the magnetosphere.

Much progress was made concerning the interaction of the solar wind (and associated shocks) with the earth. Shocks disturb the earth's upper atmosphere, ionosphere and magnetosphere. Translated the results to 55SWS, including a shock recognition algorithm designed for solar wind input data. Developed a data-driven solar wind model that predicts shock arrival time at Earth. The daily transmission of solar wind

data for operational use at the 50SWS was accomplished.

Three sensors were launched with DMSP vehicle F14 on 4 April 97. The sensors measure (at 840 km) ionospheric plasma concentrations, magnetic fields, and the flux of precipitating auroral particles.

The Charge Control System (CCS) continues to work extremely well on the DSCS B-7 vehicle. Recorded and eliminated over 100 charging events (>1500V) to date.

Valuable information was gleaned from the Photovoltaic Array and Space Power experiment plus diagnostics (PASP Plus). Ascertained the degradation of solar cell power with time and radiation dose for several different cell arrays. Determined leakage currents as functions of the positive plasma concentrations, ram/wake orientations, and vehicle potential. Determined also was the rate of arcing versus negative voltage level, ion flux, plasma density, velocity, ram angle, and array temperature.

A new theory for (combined) electron-proton auroras provides more accurate electron density profiles. This improvement will be included into operational ionospheric models like PRISM, which became operational at 55SWS last year. This specification model uses real-time data to extrapolate ionospheric conditions and the global propagation environment. The 55SWS's Voice of America Comm. Assessment Code (VOACAP) for HF propagation was modified to accept PRISM outputs. Validation is in progress at 55SWS and the new

capability becomes operational late this FY. It will greatly improve HF connectivity and reliability.

The Ionospheric Forecast Model (IFM) was given to HQ/AWS in January for transition to operational status. The IFM should be operational in FY98, providing global 12 hour forecasts of ionospheric parameters to all DoD customers.

Added the plasmaspheric populations of hydrogen and helium ions to the Global-Theoretical Ionospheric Model (GTIM). This model is the theoretical foundation of the applied model PRISM and will eventually expand the utility of PRISM to higher altitudes.

Measured the principal loss mechanisms for the ionosphere, the reactions of atomic oxygen ions with molecular oxygen and nitrogen, for the first time above 900K. The reaction rates have been found to increase at higher temperatures compared to a decrease with temperature from 300 to 900K. (Ionospheric temperature can rise to 2000K.) This finding has improved model calculations of electron concentration by 50%, thereby reducing radar range and position errors.

Installed a new algorithm at Master Control for GPS at Falcon AFB. This algorithm was based on improvements in ionospheric modeling, meets the requirement for single frequency position, and will significantly improve GPS performance.

A prototype Scintillation Network Decision Aid (SCINDA) was installed at 55SWS to provide the war-fighter with SATCOM outage regions and help him plan for such outages and/or degradation of navigation. This aid also helps identify the source of the outage: equipment failure, jamming, or ionospheric effect.

The ACTD Comm/Nav Outage Forecasting System (CNOFS) was developed for severe C<sup>3</sup>I outages near the magnetic equator. Based on research, CNOFS will

employ satellite and ground-based sensors for real-time warnings. This ACTD was ranked #1 by the AFROC last December.

The High-frequency Active Auroral Research Program (HAARP), while still under construction, was used to create an ionospheric source of ULF/ELF/VLF signals akin to those required for underground surveillance and submarine communications; study transmagnetospheric radio propagation to help characterize the near-earth space environment in conjunction with data from NASA's (solar) WIND satellite; and generate irregularities in local regions of the auroral ionosphere for coordinated studies of scintillation effects on transionospheric paths, such as satellite to ground links.

## CHANGES FROM LAST YEAR

All optical and infrared effects on Air Force Systems work has been placed in thrust eight, where the optical and infrared remote sensing work has been conducted.

Research on the contribution of cosmic rays to radiation effects on defense systems will be terminated in FY98.

Research on the following programs will be scaled back: Magnetospheric Substorms, Ultraviolet Technology, and Ionospheric C<sup>3</sup> Technology.

The BMDO-funded Space Weather and Terrestrial Hazards Program, an effort to study the sun and track space debris, was terminated. The coronagraph built for he program is available for use elsewhere.

The Improved Solar Optical Observing Network program and its initial funding profile were established. The source of funds beyond FY97 is not yet clear.

Milestones	Year	Metrics
Scintillation network Decision Aid.	FY98	Upgrade to include GPSL-Band.
Inversion of GPS to satellite propagation to determine electron density profiles.	FY98	Evaluate suitability for input to Ionospheric Forecast Models.
Forecast tool for the onset of equatorial scintillation on a global scale based on satellite data.	FY98	Provided to 55SWS.
Develop and test miniaturized Digital Ion Drift Meter (DIDM) space plasma sensors	FY98	Launch on space Test Program's (STP) Space Test Experiments Platform (STEP)-4 satellite.
Compact Environmental Anomaly Sensor (CEASE)	FY98	Launch on STP's TSX-5 satellite.
PL-GEOSpace Version 2.0 (full dynamic, data-driven models)	FY98	Delivered to 55SWS.
Quasi-dynamic radiation models	FY98	Complete transition to SMC and industry.
Coupled Ionosphere Thermosphere Forecast Model	FY98	Initial Operational Capability (IOC) at 55SWS.
Dynamic models for radiation belt electron variations during active periods	FY98	Completed.
	FY99	Launch on German satellite.
	FY99	Launch on British Defense Agency, Space Technology Research Vehicle (STRV-1 c/d.
Solar Mass Ejection Imager (SMEI)	FY99	Ready for launch.
Integrated Space Environment Model. (PLGEOSpace is a major component.	FY00	IOC at 55SWS.
Improved Operational Space Environment Models	FY00	IOC for Advanced Coupled Magnetospheric Model and Solar Prediction Model at 55SWS. IOC for Coupled Ionospheric Scintillation Model for 55SWS.

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## THRUST 8: OPTICAL SURVEILLANCE EFFECTS AND BATTLESPACE OPERATIONS

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### USER NEEDS

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Exploitation of space and combat environments is key to Air Force mission success. Important to achieving this goal is the development of techniques to accurately specify, forecast, and mitigate the battlespace environment and its effects on Air Force systems and operations. The pervasive nature of space and combat environment effects is evident in all Commands in deficiencies identified by Mission and Functional Area Plans. It is also recognized by SMC, ESC, and ASC Technology Planning Integrated Product Teams (TPIPTs). Improved specification and forecasting of the battlespace environment for theater and strategic missile detection and tracking and for air and surface target acquisition in theater engagements are needs which impact all military operations:

**Surveillance and Threat Warning** requires improved definition of target and background signatures to design new systems for missile warning, tracking, and intercept for theater and national missile defense. Technology needs for near and far term system concepts include background clutter and target data base measurements and modeling as well as discrimination algorithm development for SBIRS Geosynchronous/High Earth Orbit (GEO/HEO) and SBIRS Low Earth Orbit (LEO), the SpaceBorne Laser (SBL), and more advanced active surveillance systems.

**Combat Operations** require improved target acquisition techniques and tactical decision aids incorporating advanced theater weather forecast models for mission planning and operations support. Technology needs for air-to-surface targeting include data retrieval techniques and cloud cover models for data-denied areas in threat theaters. Improved characterization of atmospheric laser propagation for target kill is needed by the AirBorne Laser (ABL) system.

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### GOALS

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Goals for improved target-background discrimination for surveillance and threat warning include:

- Measure/characterize the infrared and optical wavelength signatures of backgrounds and targets (including missile plumes) needed to discriminate target from their backgrounds.
- Develop/validate computer codes to simulate infrared and optical atmospheric transmissions and backgrounds and celestial backgrounds to allow designers to optimize the performance of infrared and optical sensors for surveillance, tracking, and interceptor systems at minimum cost.

Goals for improved target acquisition for combat operations include:

- Exploit space-based remote sensing technologies for application to theater requirements.
- Develop Weather Impact Decision Aids to allow operational users to predict electro-optical sensor system performance for all-weather operation.
- Measure and model small-scale atmospheric effects (including optical turbulence) on high-energy laser propagation for optimizing weapon system power, range, and time-on-target.

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### MAJOR ACCOMPLISHMENTS

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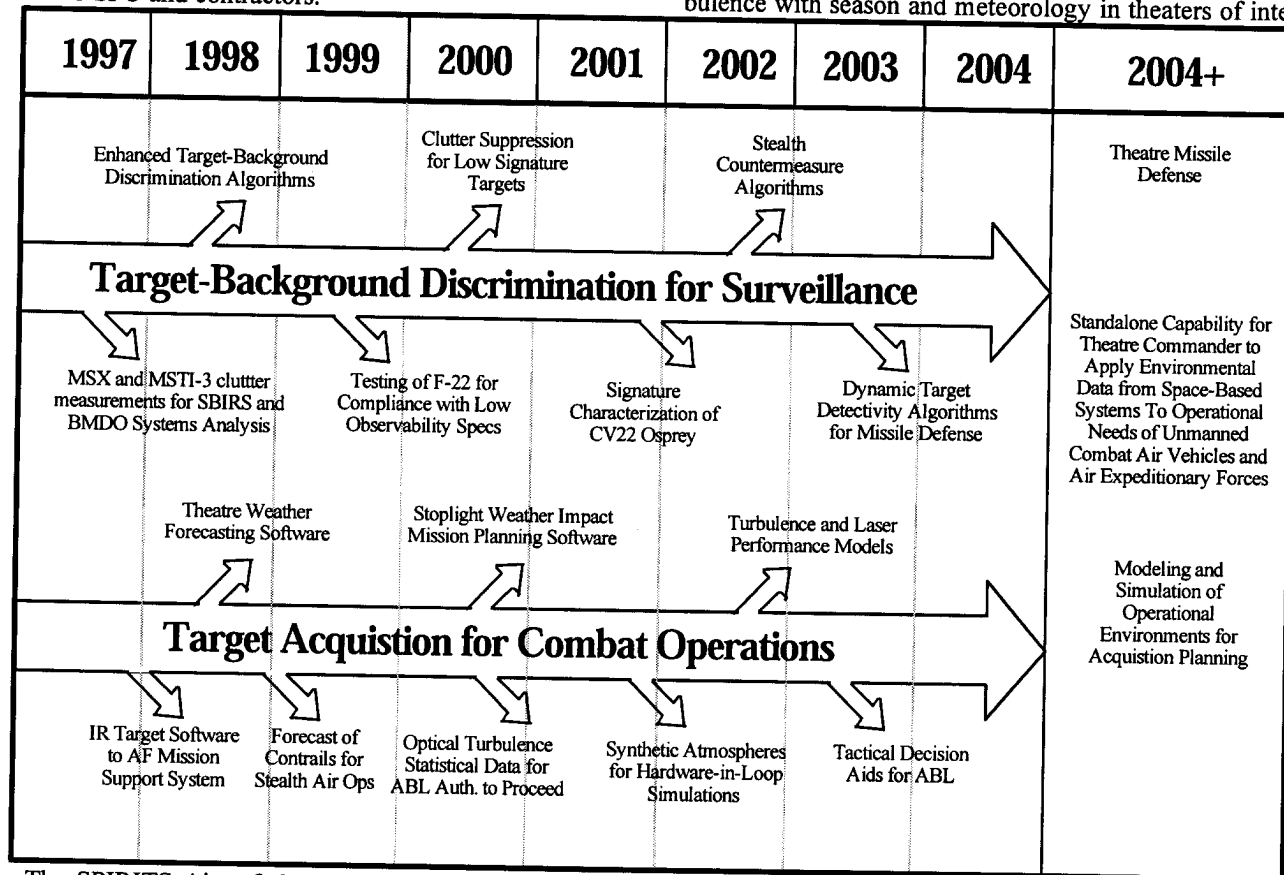
The Midcourse Space Experiment (MSX) satellite performed over 200 data collection events during the ten month cryogenic operations period to provide critically needed data on spatial structure and variability in atmospheric, cloud, and terrain infrared backgrounds and key data on celestial backgrounds. A key discovery is high clutter level in the narrow medium-wavelength infrared (MWIR) band due to atmospheric gravity waves. The measured MWIR and LWIR (long-wavelength infrared) atmospheric scenes are needed for background model assessment to support SBIRS system engineering trade studies. An infrared astrometric catalog containing the most extensive survey of IR stars was constructed to provide stellar on-board pointing and calibration for advanced space-based surveillance and tracking systems.

Under the SBIRS Phenomenology Exploitation Program (PEP), MWIR and LWIR measurements of atmospheric, cloud, and terrestrial backgrounds made by the Miniature Sensor Technology Integration-3 (MSTI-3) satellite were used to provide small and large mosaic scenes and global background clutter statistics to assess SBIRS design performance and to determine how often performance may be degraded. MSTI-3 data is also being used to validate background clutter models to provide reliable synthetic background scenes for the full range of SBIRS operational conditions and system design trade space.

Beta versions of the Synthetic High Altitude Radiance (SHARC) and SHARC Image Generator (SIG) codes to generate two-dimensional images of high altitude IR background clutter were developed to extrapolate measured background data to the full design trade space and all operational conditions for SBIRS and BMDO Theater and National Missile Defense target detection and tracking concepts. The SBIRS Model Toolkit (SMT) for

simulating cloud and terrain background scenes observed from space platforms was developed and released to the SBIRS SPO and contractors.

orographic conditions. The campaigns are part of a multi-year program to characterize the variation of turbulence with season and meteorology in theaters of inter-



The SPIRITS Aircraft 2 Version (SPIRITS-AC2) was completed and released to the defense community by the JANNAF Signatures Panel. This version supports target modules for the F-52H, Air Launched Cruise Missile (ALCM), C-130H, and C-17.

The Infrared Target-Scene Simulation Software (IRTSS) was developed to provide IR scene visualization capabilities for air-to-air and air-to-ground targets, including weather effects. The software is being tested and evaluated in a series of experiments at Eglin AFB test ranges. IRTSS will be delivered to ESC for incorporation in the Air Force Mission Support System (AFMSS).

The Cloud Scene Simulation Model (CSSM) was significantly upgraded to provide data-driven predictions of 4D scenes of cloud content. The new capability enables the use of geostationary satellite imagery and mesoscale weather model data to initialize CSSM calculations for higher fidelity simulations.

Successful field campaigns in Korea and the Middle East were conducted to measure and characterize optical turbulence effects on laser propagation in theaters of interest to the ABL weapon system. The measured atmospheric profiles provide critically needed data to specify and predict ABL performance degradation due to optical turbulence and its dependence on meteorological and

est.

## CHANGES FROM LAST YEAR

A new program to characterize missile plume signatures through clouds for early-report of theater ballistic missiles was initiated under the Emphasis Area Program sponsored by AFOSR

A new BMDO-sponsored program of aircraft measurements and model calculations to predict MWIR cloud clutter statistics for theater ballistic missile detection and tracking against stressing cloud backgrounds is being conducted as part of the BMDO Russian-American Observational Satellites (RAMOS) Program.

Budgets cuts in Program Elements 62601F and 63707F have resulted in the termination of programs in triggered lightning, tactical weather systems techniques, and WSR-88D algorithms.

Milestones	Year	Metrics
MSX and MSTI-3 IR background scenes	FY98	Background model assessment and global background clutter statistics
High-altitude background clutter code	FY98	Validated synthetic IR background scenes
Theater weather forecasting software	FY98	Transition to weather forecasting systems
Optical turbulence statistical data	FY98	Criteria for ABL Authority to Proceed
Synthetic atmospheric and cloud background scenes for new system bands	FY99	Band-dependent background clutter assessment
Cloud clutter forecasting model for new system bands	FY99	Band-dependent background clutter assessment
Infrared Target-Scene Simulation Software for mission planning and support	FY99	Operational test and evaluation
Clutter suppression methods for low signature targets	FY00	Validated filter band selection criteria

# GLOSSARY

ABL - AirBorne Laser  
 ACCESS - Advanced Composite Experimental Spacecraft Structure  
 ACTD - Advanced Concept Technology Demonstration  
 ADC - Analog-to-Digital Converter  
 AEF - Aerospace Engineering Facility  
 AFIT - Air Force Institute of Technology  
 AFMSS - Air Force Mission Support System  
 AFOSR - Air Force Office of Scientific Research  
 AL - Armstrong Laboratory  
 ALCM - Air Launched Cruise Missile  
 ALT - Anode Layer Thruster  
 AMTEC - Alkali Metal Thermal Electric Conversion  
 ARIES - Applied Research In Energy Storage  
 ASIC - Application-Specific Integrated Circuits  
 ASTP - Advanced Sensor Technology Program  
 ATM - Asynchronous Transfer Mode  
 BMDO - Ballistic Missile Defense Organization  
 C3I - Command, Control, Communications, and Intelligence  
 CAV - Common Aero Vehicle  
 CCD - Charge Coupled Device  
 CCS - Charge Control System  
 CEASE - Compact Environmental Anomaly Sensor  
 CEP - Circular Error Probable  
 CHIME - CRESS Heavy Ion Model of the Environment  
 CLEAR - Cooperative LEO Electronically Agile Radar  
 CNOFS - Communication/ Navigation Outage Forecasting System  
 CPV  
 CRRES  
 CSSM - Cloud Scene Simulation Model  
 DARPA - Defense Advanced Research Projects Agency  
 DMSP - Defense Meteorological Satellite Program

EHF - Extremely-High Frequency  
 E-O - Electro-optical  
 ESA - European Space Agency  
 FDDI - Fiber Optic Digital Data Interface  
 GaAs - Gallium Arsenide  
 GEO - Geosynchronous Earth Orbit  
 GPS - Global Positioning Satellite  
 GTIM - Global-Theoretical Ionospheric Model  
 HAARP - High-frequency Active Auroral Research Project  
 HAN - Hydroxyl Ammonium Nitrate  
 HDBTDC - Hardened and Deeply Buried Targets Defeat Capability  
 HDI - High-Density Interconnect  
 HEDM - High Energy Density Material  
 HEO - High Earth Orbit  
 HF - High Frequency  
 HgCdTe - Mercury Cadmium Telluride  
 ICBM - Inter-Continental Ballistic Missile  
 IFM - Ionospheric Forecast Model  
 IMU - Inertial Measurement Unit  
 INS - Inertial Navigation System  
 IPV - Inertial Penetrator Vehicle  
 IR - Infrared  
 IHRPT - Integrated High Payoff Rocket Propulsion Technology  
 IRTSS - Infrared Target-Scene Simulation Software  
 ISR - Intelligence, Surveillance, and Reconnaissance  
 ISTD - Integrated Space Technology Demonstrations  
 JANNAF - Joint Army, Navy, NASA, Air Force  
 LASRE - Linear Aerospike SR-71 Experiment  
 LED - Light Emitting Diode  
 LEO - Low-Earth Orbit  
 LWIR - Long-Wave Infrared  
 M&S - Modeling and Simulation  
 MAGIC - Multimission Advanced Ground Intelligent Control  
 MAGR - Miniature Advanced GPS Receiver

MANTECH - Manufacturing Technology  
 MAP - Mission Area Plan  
 MAPLE - Microsystems And Packaging of Low-Power Electronics  
 MCM - Multichip Module  
 MEMS - Microelectromechanical System  
 MSX - Mid-Course Sensor eXperiment  
 MTD - Missile Technology Demonstration  
 MWIR - Mid-Wave Infrared  
 NOAA - National Oceanic and Atmospheric Administration  
 OSP - Orbital/Suborbital Program  
 OTH - Over The Horizon  
 PEP - Phenomenology Exploitation Program  
 PL - Phillips Laboratory  
 PPT - Pulsed Plasma Thruster  
 PRISM - Parameterized Real Time Ionospheric Specification  
 QWIP - Quantum-Well Infrared Photodetector  
 RAMOS - Russian-American Observational Satellites  
 RF - Radio Frequency  
 RL - Rome Laboratory  
 S&T - Science and Technology  
 SBIR - Small Business Innovative Research  
 SBIRS - Space-Based InfraRed System  
 SBL - Space-Based Laser  
 SBR - Space-Based Radar  
 SCINDA - Scintillation Network Decision Aid  
 SEU - Single Event Upset  
 SHARC - Synthetic High Altitude Radiance  
 SIG - SHARC Image Generator  
 SMC - Space & Missile Systems Center  
 SMEI - Solar Mass Ejection Imager  
 SMT - SBIRS Model Toolkit  
 SOX - Solid Oxygen  
 SPEAR - Space Electronically Agile Radar  
 SPIRITS

SPREE - Shuttle Potential and Return Electron Experiment  
STIG - Space Technology Inter-agency Group  
STRV - Space Technology Research Vehicle  
TA - Technology Area

TAP - Technology Area Plan  
TMD - Theater Missile Defense  
TOC - Tactical Operations Center  
TPIPT - Technology Planning Integrated Product Teams  
TRAM - Transmitting/Receiving Antenna Module

TSS - Tethered Satellite System  
UHF - Ultra-High Frequency  
VOACAP - Voice of America Communication Assessment Code  
WL - Wright Laboratory

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